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IEMCAP ANALYSIS OF THE XM-1 TANK.(U)

SEP 82 T E BALDWIN, D R PFLUG, M K BARTLEY DAAK80-81-C-0030

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CECOM-81-0030-F

AD A119866

IEMCAP Analysis of the XM-1 Tank

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September 1982

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Prepared for
CENTER FOR COMMUNICATIONS SYSTEMS

CECOM

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CECOM-81-0030-F	2. GOVT ACCESSION NO. AD-A229866	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IEMCAP Analysis of the XM-1 Tank		5. TYPE OF REPORT & PERIOD COVERED Final Report 29 January 1981 to 24 April 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas E. Baldwin, Jr. Donald R. Pflug, Jr. Mildred K. Bartley		8. CONTRACT OR GRANT NUMBER(s) DAAK80-81-C-0030
9. PERFORMING ORGANIZATION NAME AND ADDRESS Atlantic Research Corporation 5390 Cherokee Avenue Alexandria, Virginia 22314		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162701AH92PE14
11. CONTROLLING OFFICE NAME AND ADDRESS CECOM Attn: DRSEL-COM-RY-2 Ft. Monmouth, New Jersey 07703		12. REPORT DATE September 1982
		13. NUMBER OF PAGES 92
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release
Distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

(Electromagnetic Compatibility Analysis Program)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

IEMCAP
Electromagnetic Compatibility
Interference
EMC Analysis Techniques
EMC Measurement Techniques
Sensitivity Analysis
Intrasystem Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report concludes the results obtained during the IEMCAP Analysis of the XM-1 Tank Project. The period covered was 29 January 1981 to 24 April 1982. The major effort consisted of applying the Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) to the analysis of the XM-1 tank, identification of problem areas and limitations of IEMCAP, XM-1 system definition, data requirements and an IEMCAP input data sensitivity analysis.

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Unclassified

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1.0 INTRODUCTION

CECOM is currently developing system electromagnetic compatibility (EMC) analysis tools and measurement techniques that will allow the prediction of intra-system electromagnetic interference (EMI) during system design. In addition, they may help to speed up system EMI testing by identifying potential EMI problems, and hence permitting the tailoring of test plans. In response to previous Tank Science and Technology Board interest in this program, and after consultation with the Armor Center, it is planned that the XM-1 tank design be used as part of the technology validation phase of the intra-system analysis/measurement techniques program.

The objective of this contract is to apply the Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) to the analysis of the XM-1 tank for the purpose of evaluating and validating the overall methodology of the CECOM intrasystem analysis/measurement techniques program in general, and the draft EMI measurement standard contained in a CORADCOM development report.[1]

Specific items to be addressed in performing the effort include the following:

- Identification of problem areas and limitations of IEMCAP.
- Determine data requirements for an IEMCAP analysis of the XM-1. The objective is to develop a cost-effective data requirements methodology that may be applied to other Army systems.
- Compare results of the IEMCAP analysis to MIL-STD-462 and other EMC test results.
- Evaluate the CECOM draft EMI standard.
- Develop a methodology for incorporating an IEMCAP type analysis into the Army system development cycle.

This report is the final report on the subject contract. Section 2.0 presents the executive summary. A detailed description of the problem areas and limitations of the IEMCAP is presented in Section 3.0. The XM-1 analysis is presented in Section 4.0. The XM-1 system definition, IEMCAP data requirements and data availability on the XM-1 are discussed. An IEMCAP input data sensitivity analysis is described in Section 5.0. In particular, the problems of identifying the wire bundling

and wire characteristics required by the IEMCAP are addressed in considerable detail. Section 6.0 presents a discussion on who should be responsible for performing an IEMCAP analysis on Army systems; Prime Contractor or independent consultant. Appendix I presents an overview of the IEMCAP. Appendix II contains a bibliography used in this effort.

2.0 EXECUTIVE SUMMARY

The use of a computer EMC analysis program, such as that provided by the IEMCAP, to identify critical system frequencies and to define the EMC requirements at those frequencies appears feasible. An in-depth look at the input data requirements for IEMCAP, limitations of the present program, and applicability of IEMCAP for analyzing the EMC of an XM-1 tank system is presented. The input data required for IEMCAP does not appear to be overly excessive in terms of the amount of data required to perform a system EMC analysis. However, based on the experience with the XM-1 tank obtaining some of the required data, e.g., in band emissions and susceptibilities, or wire type and routing, may be difficult to obtain in all the various stages of system development and thus there remains a questionable area on how to get the necessary data. Also, a cost effective data collection philosophy cannot be established for Army system procurements based on this study.

There are several limitations associated with the present IEMCAP. These limitations in the program may be considered as resulting from the following:

- State-of-the-Art Modeling Capability
- Stringent Computer Requirements
- Air Force Systems Requirements

Overall, the program limitations are as appropriate to applying IEMCAP to Army systems as they are to Air Force systems.

IEMCAP is a computerized analysis process which can be used to establish and maintain cost-effective interference control throughout the life cycle of systems composed of communications and electronics equipment. Fundamental to the major options of IEMCAP are the following built-in capabilities:

- Provides system data base
- Complete description of system emissions, susceptibilities, EM coupling, and EMI
- System specifications
- Defines measurement requirements

One of the most significant capabilities of IEMCAP is the generation of a system data base which can be continually maintained and updated to follow system design changes/modifications. The data base created by the IEMCAP will result in rapid and economical analysis of modifications.

A series of sensitivity analysis calculations were performed using the wire-to-wire coupling analysis routine from the IEMCAP code. The following wire configurations were analyzed:

- both wires unshielded
- emitter wire single shielded, receptor wire unshielded
- emitter wire unshielded, receptor wire single shielded
- both wires single shielded
- emitter wire unshielded, receptor wire double shielded.

A selected set of parameters important to the wire-to-wire coupling program were systematically varied. The parameters were:

- average wire separation
- wire segment height
- wire segment length
- pigtail length
- shield grounding configuration
- reference wire return path

Average wire separation and segment length seemed to be the most sensitive. Average wire separation coupling variations were from 5.5 - 10dB for each 100% change in the separation parameter. Similar changes in segment length provided a change in coupling of 5 - 7 dB. Important changes were noticed in coupling when shields were double end grounded. Variations in segment length for segments involving double end grounded shields caused complicated coupling variations including curve crossings and oscillations. The cause of this behavior is not known with certainty but it is suspected that wire model breakdown may be occurring. Additional effort in this area is very desirable.

The wire-to-wire analysis program in IEMCAP uses lumped circuit element models to predict the wire-to-wire coupling. Such models are adequate only for circuits that are electrically small (circuit dimensions << wavelength). In performing the sensitivity analysis, variations in

circuit dimensions (e.g., wire length, height) also should be electrically small. This proved to be the case only over certain frequency ranges. Consequently, the guidelines have frequency ranges associated with them.

The wire-to-wire analysis program is restricted currently to one wire segment. A generalization of the code is possible in which a wire could be divided into several segments (each electrically small) and be allowed to have branches. The coupling in each segment and branch would be computed and the total coupling approximated as a sum of the coupling over all segments and branches. In this way an electrically long or complicated wire bundle can be approximated quite well. In future efforts, the program could be expanded to include these capabilities.

The wire-to-wire program was carefully analyzed and several programming errors found and corrected. These corrections have lead to better agreement with experimental wire coupling results than had previousl been the case. It is felt that further work in this area is desirable especially in view of the strange results obtained with wires whose shields are double end grounded.

A variable pigtail length was added to the code. The pigtail length can now be any length including no pigtail. The code is still somewhat restricted by the fact that both wires must have the same pigtail length. This restriction could be resolved in a future development effort.

The wire-to-wire coupling analysis program requires wire data in considerable detail. This information may not be available in every case consequently, as discussed above, a limited sensitivity analysis was performed using the various data parameters required by the wire-to-wire coupling program. A data parameter or small group of data parameters were varied while the rest of the data parameters were held fixed. The result of this analysis will allow the user to estimate the uncertainty in the coupling calculation due to an uncertainty in an input data parameter.

Based on this study, it is recommended that several modifications to the IEMCAP be implemented for handling Army systems. The recommended modifications consist of the following:

- System Geometry Structure
- Antenna Coupling Models which Account for Diffraction and Shading Factors Associated with Army Structures
- Specification Generation Philosophy
- Wire-to-Wire Coupling Models for Cases with Limited Wire Data Characteristics

3.0 PROBLEM AREAS AND LIMITATIONS OF IEMCAP

In order to use IEMCAP (see Appendix I) in an efficient and effective manner, it is extremely important to understand all of the problem areas and limitations associated with the program. This is particularly important when the program is applied to vehicles other than aircraft/aerospace types for which the program was initially designed. Particular emphasis is placed on determining the limitations of the existing IEMCAP coupling models for application to tank type systems. Some of the important limitations of IEMCAP are discussed below.

The system approach of the IEMCAP involves identifying all ports in the system having potential for signal coupling. These ports are categorized as emitters and receptors with associated signal coupling paths. The function of the IEMCAP is to determine, by linear analysis, (no nonlinear effects such as desensitization, intermodulation etc. are computed by IEMCAP) whether signals from one or more emitters unintentionally coupling to a receptor will impair the receptor's required operation. It is therefore necessary for the system model to include some characterization of the receptor's performance degradation due to interference signals. The IEMCAP assumes that average power of signals is the criterion appropriate for assessment of an interference condition in receptors.

The assumption in the IEMCAP system model that receptors are power vulnerable devices implies that their performance can be characterized in terms of average power of signals present at their input. The result of integration of signal power spectral densities is some power level at the receptor's detector which may or may not exceed a threshold power level defined for that receptor. This total power level at a receptor's detector will, in general, be a composite of desired signal power, thermal noise power and system induced interference power.

In order to simulate the physical operation of actual power vulnerable receptors the IEMCAP includes a routine for mathematically integrating the interference power spectral density present at the receptor's inputs, weighted by the receptor power transfer function, in its assessment of the interference power level at the receptors detector. The model forms the ratio of this computed interference power level with the tolerable interference power level assigned to the receptor. This interference power ratio is called the "Integrated EMI Margin" (I.M).

When expressed in decibels, a positive I.M. is considered an interference condition while a negative I.M. is generally considered a compatible condition.

A further aspect of the IEMCAP system model that needs discussion is the manner in which broadband emission spectra are treated in the program. The integrated EMI margin is evaluated by a weighted integral of an emitter's power spectral density in watts per hertz received at the input port of a receptor. Broadband emission limits, however, are not specified in terms of power spectral density but in terms of the quantity measured by a standard EMI test receiver, such as an Empire Devices NF-105; namely, the current spectral level in microamps per megahertz. The current spectral level is a measure of the peak current contained in the instrument bandwidth.

There are some receptors in systems, being utilized more as technology advances, that are not adequately represented by the power vulnerability assumed in the IEMCAP system model. These threshold vulnerable devices must have more information about their actual modes of excitation and the IEMCAP should make provisions for an option capable of predicting the system effects on such devices. An approach to providing the IEMCAP with a logical alternative analysis using peak current margins, for threshold devices is presently being evaluated in another program. A key aspect remaining to be adequately treated is the proper assignment of susceptibility levels for such devices. There appears currently to be a lack of consensus in the electronics community about the degree of vulnerability to these types of system elements to EMI.

During the calculation of the coupling from emitter ports to a particular receptor port, a check is made to determine if any wires connected to any of the emitter ports are in the same bundle (no bundle-to-bundle coupling in IEMCAP) and run as wires connected to the receptor port. If there are such wires, the wire-to-wire coupling routine is called. This routine computes the spectral voltages induced in the receptor circuit by the emitter circuit. These calculations are performed on a pair basis (only one emitter circuit considered to couple with the receptor circuit for each calculation) with the effects of all other circuits neglected during this calculation. Each possible pair coupling is computed in turn and the total coupling is calculated by summing all of the pair couplings without regard to phase. It should be noted that the validity of this wire-to-wire coupling model has been verified by experimental data.

For frequencies where the wire length is short compared to a wavelength, the models provide an accurate representation of the actual coupling situations. However, for the frequencies where the wire lengths are comparable to or greater than the wavelength, the actual coupling is very sensitive to line length and no simple model is available for modeling the exact coupling. In this frequency range, the models approximate the envelope of the coupling curve so that the predicted coupling is never less than the actual.

The basic model for wire-to-wire coupling considers capacitive coupling due to the interwire capacitance and inductive coupling due to the mutual inductance between the wires. This model uses the approximation that the total coupling can be computed as the sum of the capacitive and inductive coupling computed separately.

The basic antenna model for medium and high gain antennas is a three sector representation corresponding to a mainbeam, major sidelobe and backlobe. Each sector subtends a solid angle in the unit sphere and has an associated quantized antenna gain. This representation of an antenna is specified for the designed frequency and all locations associated with a given antenna. That is, the IEMCAP assumes that antennas are frequency independent and the placement of the antenna on the structure does not distort the radiation characteristics. Polarization effects are neglected in the antenna coupling calculations.

The intravehicular propagation model associated with the IEMCAP is based on aircraft and spacecraft/missile systems. This model calculates the propagation loss associated with an electromagnetic coupling path when both source and receptor are located on the same craft. Associated with this model is a vehicular model for determining antenna separation distances. The vehicular model determines the combination of straight lines, conical spirals and/or cylindrical spirals that gives the shortest distance between two antennas over a spacecraft or aircraft surface. The distances computed are used in the fuselage (cylindrical) shading and/or wing diffraction computations to determine the total shading factor portion of the propagation model. Other geometrical structures, e.g., generic tank type geometrics must be handled by "fooling" the program. That is, the parameters used by IEMCAP to determine the aircraft/spacecraft geometry must be "dummied-up" by inputing values that will generate an approximate structure.

A typical system (aircraft, spacecraft or ground system) may contain thousands of ports. If every emitter port had to be analyzed in conjunction with every receptor port, the run time, main memory size and file storage requirements would be prohibitive for most computer systems. A compromise set of conditions was established and the capacity of IEMCAP with regard to run size is given in Table I-2. For systems which exceed those limits, multiple computer runs are required.

The defined frequency range of analysis for the IEMCAP is 30 Hz to 18 GHz. These limits are based on the prestored models associated with the program such as the MIL-STDS.

4.0 XM-1 ANALYSIS

This section will describe the basis for data collection and analysis on the XM-1. The IEMCAP data requirements are presented. The XM-1 critical systems/subsystems to be included in the intrasystem analysis process are discussed.

4.1 IEMCAP Input Data Requirements

IEMCAP is designed to perform an EMC analysis on a system throughout the various stages of the system's life cycle from conceptual studies of new systems to field modification on existing systems. To accomplish this task, the IEMCAP generates a system data base which can be continually maintained and updated to follow system design changes/modifications. Initial inputs to the data base must be provided by the user. The input data base structure is shown in Figure 4.1. As shown by the figure, there are four basic levels in the hierarchical structure which are the following:

- System
- Subsystem
- Equipment
- Port

The IEMCAP definition for each of these levels is as follows.

Systems. The system data defines the system type (aircraft, spacecraft, ground etc.), overall physical dimensions, coordinate system parameters, and basic analysis parameters applying to the entire system. It aslo includes common model parameter tables. These tables contain basic parameters for apertures, antennas, filters, and wire characteristics which have multiple use throughout the system. They are referenced at the port level so that the basic parameters are specified only once. For example, a particular antenna type may be used for several different ports in the system. The antenna physical dimensions, mainbeam shape, gain, etc., are specified in the system data along with an identifying name. In the port data, this name is referenced, and only the antenna coordinates and mainbeam orientation are specified for each of the ports using the antenna.

Subsystem. A subsystem consists of well defined parts of a system usually performing a related task. A radar package and a central computer complex are examples of subsystems. This level is defined for convenience in organizing

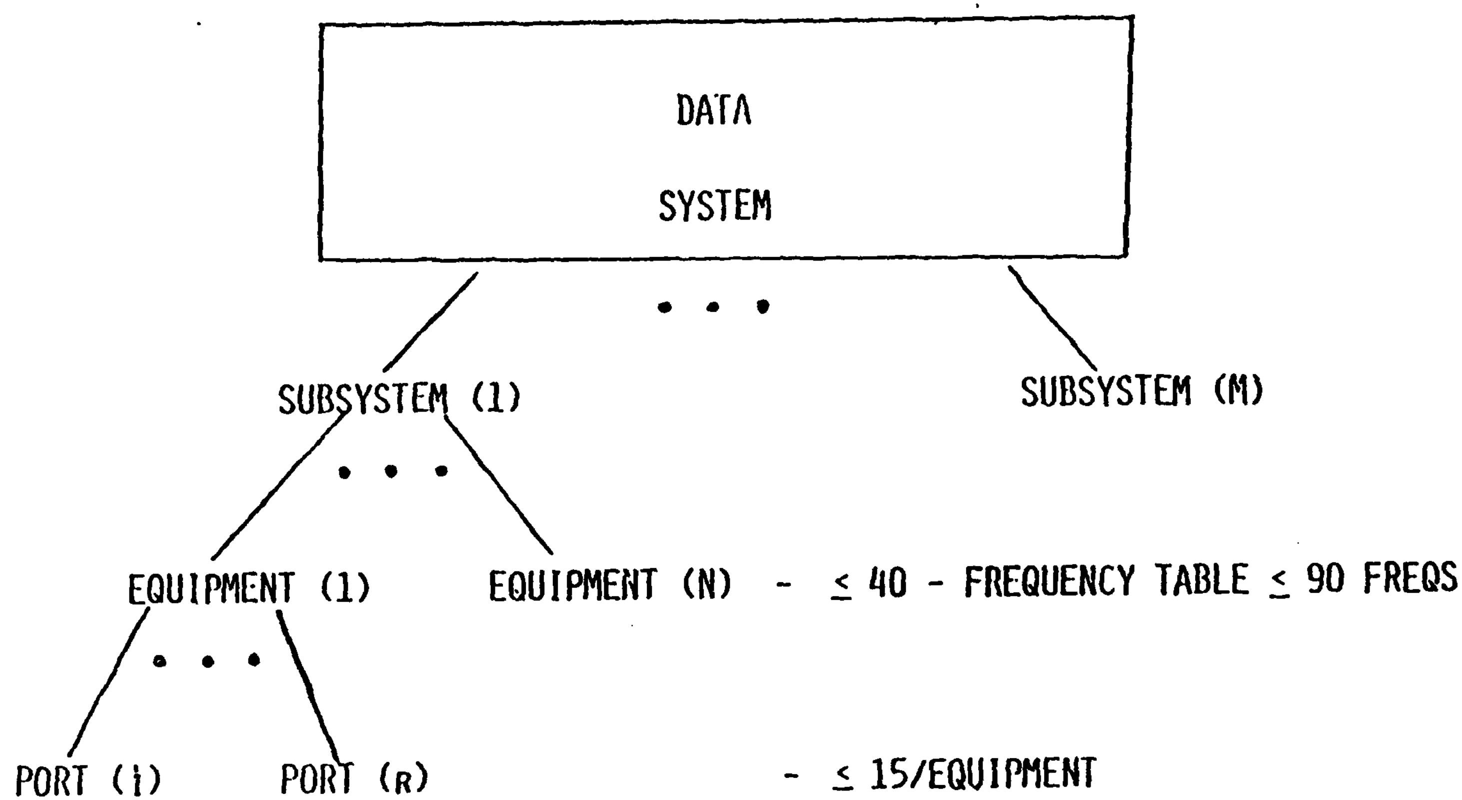

Figure 4.1 Data Base Structure.

the data and is not a functional level within the program. Hence, equipments need not be specified with reference to a subsystem. A minimum of one subsystem must be identified.

Equipment. An equipment is a physical box located in the system, such as a transmitter unit.

Port. A port is a point of entry or exit of electromagnetic energy from an equipment. A port may be connected to an antenna or to a wire. Leakage into and out of the equipment case is also a port. A port may be designated as a source (emitter), a receptor, or both. The analyses are performed on a port-to-port basis. All ports within the same equipment are assumed compatible with each other.

In addition to the above data the wire bundle data is also organized into a heirarchy, which allows complex wire routings to be analyzed. The components are as follows:

Bundle. A bundle is a group of wires which, for some portion of their lengths, run parallel to each other.

Bundle Point. A point in the system at which a bundle branches or changes direction. Between bundle points wires are assumed to run in straight lines, and no branching occurs.

Segment. A segment is a section of a bundle running between points. Segments are designated by giving the bundle points. Within a segment the wires are assumed to run parallel. A segment may also run by a dielectric aperture and be exposed to energy from external antennas and environmental electromagnetic fields.

Wire. A wire connects two or more ports. Its routing is specified by designating the bundle points through which it passes for which segments have been defined. The wire physical parameters are given by referencing the Wire Characteristics Table, which is specified at the system level.

The remainder of this subsection will discuss the system, subsystem, equipment and port requirements and wire routing in more detail.

4.1.1 System Data

The system data defines certain physical aspects of the system and specifies basic analysis parameters applying to the entire system. The basic systems appropriate to IEMCAP are aircraft, spacecraft and ground systems. The parameters required to identify each of these systems is

given below

- AIRCRAFT - Conical nosed cylinder with wings. A flat or round bottom cylindrical model may be used to approximate the vehicle shape. Radii associated with the cylinder and conical sections are required input data. Wingroot and wingtip coordinates must be provided.
- SPACECRAFT - Same as aircraft but without wing parameters.
- GROUND - A ground station such as a hut, or other collection of ground based communications-electronics systems. This system is associated with a finitely conducting ground plane and the conductivity (σ) and relative permittivity (ε_r) must be specified.

Any convenient coordinate system may be used for the above. However, the IEMCAP User's Manual suggests that for aircraft coordinates use the commonly accepted aircraft system of butt line, water line and fuselage station. For spacecraft and ground systems use the rectangular (x, y, z) coordinate systems.

Another input option available at the system level provides for identifying an ambient electromagnetic field environment for the system. The ambient field levels may be specified both external and internal to the system. Wires exposed by apertures in the system structure and antennas are exposed to the external fields. Equipment cases and wires inside the system are exposed to the internal fields. Either the external or internal fields or both may be specified. If the external field only is specified, the internal field defaults to 40 dB less than the external field. If the internal field only is specified, the external field defaults to 40 dB greater than the internal field. If neither field is specified, the default value is zero and no environmental field calculations are performed.

As indicated above, there are certain common model parameters specified at the system data level. This data specifies parameters for apertures, antennas, filters and wire characteristics used throughout the system. Basic parameters must be identified for each aperture antenna, filter and wire associated with the system. An aperture is defined as any non-metalic opening (symbolic or actual) in the structure in which EM coupling to a wire(s) is to be considered. Apertures expose wire bundle segments to external electromagnetic energy from antennas and any defined environmental fields. The required aperture parameters are aperture identification code, coordinates of the center of the aperture, width and length of the aperture and location on the structure if it is an aircraft.

Antenna common model parameters are a function of the antenna type. Antennas for IEMCAP purposes are categorized as low, medium and high gain. The low gain antenna types consist of the dipole, whip, slot and loop. The specific medium and high gain antennas identified for the IEMCAP are parabolic dish, log periodic, horn, phased array and spiral. However, a user may model any antenna via the medium/high gain model by using one of the model codes for the above antenna types as a pseudo model. Each antenna in the system must be identified by a code, IEMCAP model, primary polarization and appropriate physical dimensions. Antenna gain parameters are required input data for the medium and high gain antenna types. Each of these parameters are defined below:

- antenna length (low gain)
- largest antenna dimension
- design frequency maximum antenna gain
- 3-dB vertical beamwidth of the mainbeam
- 3-dB azimuthal beamwidth of the mainbeam
- major sidelobe gain
- major sidelobe beamwidth
- backlobe gain

The above data provides for a three dimensional three-sector representation for the medium and high gain antennas. The three sectors correspond to the antenna mainbeam, major sidelobe and backlobe regions. A two sector representation may be specified by defining the mainbeam

characteristics and the major sidelobe region. The major sidelobe gain and beamwidth are specified such as to encompass all but the mainbeam region of the antenna.

The filter common model parameters are a function of the prestored models. The prestored filter models consist of a single tuned stage, transformer coupled stage, Butterworth tuned, lowpass, highpass, bandpass and band reject. The required input data for each model is a filter identification code, and the type and data as defined below:

- Single tuned stage
  - tuned frequency
  - bandwidth
  - insertion loss
  - maximum isolation
- Transformer coupled stage
  - tuned frequency
  - insertion loss
  - maximum isolation
  - circuit Q (quality factor)
  - circuit coupling factor (m)
- Butterworth tuned
  - tuned frequency
  - bandwidth
  - maximum isolation
  - insertion loss
- Lowpass
  - upper break point frequency
  - insertion loss
  - maximum isolation
- Highpass
  - lower break point frequency
  - insertion loss
  - maximum isolation
- Bandpass and Band reject
  - lower break point frequency
  - upper break point frequency
  - insertion loss
  - maximum isolation

The above models represent filters as ideal, lossless networks, made up of only reactive elements (capacitors and inductors). When a filter is used in a circuit, however, it "sees" an input impedance at the source end and an output impedance at the load end, both of which contribute to the overall transfer function between source and load. In the absence of a filter, the maximum power is delivered to the load when the load impedance matches the source impedance. For equal source and load resistances, the maximum power delivered to the load is half the total power, the other half being dissipated in the source resistance. The insertion of a filter between the source and load selectively attenuates the signal delivered to the load at a given frequency.

The filter transfer models calculate the "insertion loss" in dB provided by a filter at a given frequency, i.e., the reduction in delivered power due to insertion of a filter. Thus the insertion loss of the single tuned filter at the resonant frequency is 0 dB, i.e., the insertion of the filter does not attenuate the signal delivered to the load at that frequency.

Practical filters are not ideal, lossless networks; there are always dissipateive elements which affect filter performance. Consequently the filter models provide for a minimum insertion loss to represent actual dissipation at the tuned frequency or in the passband. The filter models also provide a maximum insertion loss or isolation to represent the departure from the ideal rejection in the rejection band. The minimum and maximum insertion loss provide lower and upper bounds for the filter transfer function.

The wire common model parameters consists of a table of general wire characteristics which are referenced for specific wires in a given wire bundle. The wire characteristics table was designed to be applicable to general systems to work in conjunction with the models for computing coupling between circuit pairs even when the connecting wires have a relatively complex configuration (such as shielded, twisted pairs). For the IEMCAP, the circuits for which models have been developed include:

- Single (unshielded) wires with ground return
- Twisted pair circuits (balanced or unbalanced)
- Shielded wires (single or double shield) with single or multiple grounded shields
- Shielded twisted pair circuits (balanced or unbalanced, single or double shield) with single or multiple grounded shields.

These models are valid for both emitter and receptor circuits and any type of emitter circuit may be analyzed with any type receptor circuit. The input data for the above wire types includes a wire type identification code and the data corresponding to the wire types as defined below.

- Unshielded Wires
  - conductor diameter
  - conductor conductivity
  - insulation thickness
  - insulation dielectric constant
  - twisted pair or single wire
- Single Shielded Wires
  - conductor diameter
  - conductor conductivity
  - insulation thickness
  - insultation dielectric constant
  - shield internal diameter
  - shield thickness
  - shield jacket thickness
  - shield-to-conductor capacitance
  - twisted pair or single wire
- Double shielded wires (shields are separated by dielectric)
  - conductor diameter
  - conductor conductivity
  - insulation thickness
  - insulation dielectric constant
  - inner shield internal diameter
  - inner shield thickness
  - inner shield jacket thickness
  - shield-to-conductor capacitance (to inner shield)
  - outer shield internal diameter
  - outer shield thickness

4.1.2 Subsystem Data

The subsystem identification is the second level of the hierarchical structure which exists in the IEMCAP data base structure. The subsystem level provides a means for organizing groups of equipments performing related tasks. For example, an aircraft system might have a navigation subsystem which is composed of several equipments such as a transmitter-receiver-unit, a display unit, and a navigation computer. For IEMCAP purposes this navigation subsystem should be identified by an identification code with the physical boxes comprising the subsystem defined as equipments. Other subsystems within the aircraft would be defined in a similar manner.

The IEMCAP requirements stipulate that at least one subsystem must be provided for a given system. More than one subsystem is allowed per system and the program user has total control over the number of subsystems to use.

The only input data requirement for the subsystem level is an identification code.

4.1.3 Equipment Data

For IEMCAP purposes, the physical boxes comprising a subsystem are defined as equipments. Equipment data is represented as the third level in the hierarchical input data structure. This level of input data provides specific parameters which pertain to the overall equipment characteristics. The data identified at the equipment level are used at the port source and receptor level.

Each equipment within a subsystem must be assigned an identification code, MIL-STD specification, compartment identification code, security classification, coordinates and fixed or adjustable EMC limits. The equipment identification codes are user assigned and must be unique within a given subsystem. The MIL-STD Specifications are prestored models in IEMCAP and an option of MIL-STD-461A (Notice #3) or MIL-I-6181D is currently available.

Each equipment in a system must be assigned a compartment identification code. IEMCAP uses the equipment compartment identification to ascertain case-to-case (box-to-box) coupling calculations. Only equipments with identical compartment identification codes are considered for case-to-case coupling computations. Therefore, at least one compartment must be specified for a system. However, the user may elect to have the program omit

the case-to-case calculations between isolated equipments within the system by assigning them to different compartments.

The locations of the quipment within the system is determined by specifying the coordinates of the center of the physical box representing the equipment. The units for the equipment coordinates are the same as those described in Section 4.1.1.

For each equipment in a system, an option of fixed or adjustable EMC limits is provided. If the option to adjust the EMC limits is chosen, the nonrequired port spectra are adjustable by the specification generation routines to the limit defined at the port source or receptor level. If fixed EMC limits are used, then none of the equipment port spectra are adjusted. This parameter is ignored for all IEMCAP execution options except the specification generation run.

In addition to the above equipment input parameters, a spectrum sample frequency table must be defined for each equipment in the system. This equipment frequency table is applicable to all port spectra within a given equipment. The equipment frequency table may be defined by default values, user inputs or a combination of default and user inputs. The input parameters for the equipment frequency table are

- lowest frequency to be considered (default 30 Hz)
- highest frequency to be considered (default 18 GHz)
- number of frequencies per octave (default = 3)
- maximum number of frequency $\leq$ 90 (default = 90)
- user specified frequency in ascending order $\leq$ 88 (must be at least two less than the maximum number of frequencies specified)

4.1.4 Port Data

The physical boxes comprising the subsystem are defined as equipments. Electromagnetic energy may enter or leave these equipments via ports. Ports are designated as emitters or receptors or both. An emitter port generates electromagnetic energy and a receptor port is susceptible to electromagnetic energy. Ports may exist in an equipment as intentional or unintentional. An example of an unintentional port is leakage into or out of an equipment case. An example of an intentional port is a connector pin through which AC power, signals, etc. are brought into or out of the equipment. Such ports are connected to wires or antennas. The port input data for wire and antenna connected ports consists of port identification codes and the following:

- Wire Connected Port
  - Wire bundle identification
  - Wire identification code (same as system level identification)
  - Bundle point identification
  - Return path of signal
  - Shield termination
  - Aperture exposed wire
  - Termination resistance
  - System displacement factor for source
  - System displacement factor for receptor
  - Filter identification code (same as system level identification)
- Antenna Connected Port
  - Antenna identification code (same as system level identification)
  - Direction of mainbeam peak (Vertical angle)
  - Direction of meainbeam peak (Azimuth angle)
  - Antenna coordinates (Center of antenna in same units as specified in Section 4.1.1

- Antenna location on wing if system is an aircraft
- Termination resistance
- System displacement factor for source
- System displacement factor for receptor
- Filter identification code
  (Same as system level identification)

To complete the port specification input data a port must be designated as a source, receptor or both and additional data specified as a function of port type. IEMCAP models the following port types

- Radio frequency
- Power
- Signal
- Control
- Electro-explosive devices
- Equipment case

The specific data required for each port type is shown below.

- Radio Frequency Port
  - Adjustment limit displacement from the initial spectrum level. The Specification Generation Routine (SGR) can adjust the spectrum this number of dB from its initial amplitude. Must be positive.)
  - Lowest carrier frequency*
  - Highest carrier frequency*
  - Minimum sensitivity (receptor)
  - Bandwidth of Channel
  - Modulation/signal code
    - Continuous wave
    - Pulse duration modulation
      - Pulse repetition
    - Non Return to Zero (NRZ) pulse code modulation
      - Pulse repetition
    - Biphase pulse code modulation
      - Pulse repetition
      - Modulation index

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* Note lowest carrier = highest carrier frequency provides tuned frequency carrier condition.

- Pulse position modulation
  - Pulse repetition
  - Pulsewidth
- Conventional telegraph
  - Words per minute
  - Tone frequency
- Frequency-shift keying
  - Pulse repetition
  - Difference between upper and lower oscillator frequencies
- Pulse amplitude modulation
  - maximum frequency deviation
- Radar (pulsed RF)
  - Rectangular
  - Trapezoid
  - Cosine squared
  - Gauss
  - Chirp
  - Pulse parameters required
  - Pulsewidth
  - Rise time
  - Fall time
  - Pulse compression ratio (neg. if frequency deviation is negative)
- Amplitude modulation
  - Double sideband suppressed carrier
  - Single sideband, lower
  - Single sideband, upper
  - Frequency modulation
  - Local oscillator leakage from receivers
    - Signal type code
      - Voice
      - Clipped voice
      - Telegraphy digital
  - Harmonic displacement level (source) relative to fundamental for the 2nd, 3rd, ... up to 10th

- Power Port
  - Adjustment limit displacement from initial spectrum level
  - Voltage (RMS) of line
  - Frequency (0 to DC)
  - Highest harmonic
  - Number of phases
  - Ripple or noise spectrum
- Signal and Control Ports
  - Spectrum adjustment limit displacement from initial spectrum level
  - Lowest required frequency
  - Highest required frequency
  - Modulation/signal code
    - Pulse duration
      - Pulse repetition rate
    - Nonreturn to zero pulse code modulation
      - Pulse repetition rate
    - Biphase pulse code
      - Pulse reptition rate
      - Modulation index
    - Pulse position modulation
      - Pulse repetition rate
      - Pulse duration
    - Morse telegraphy
      - Words per minute
      - Tone frequency
    - Pulse amplitude modulation
      - Pulse repetition rate
      - Pulse duration
      - Exponential decay spike
        - Pulse repetition rate
        - Pulse duration
      - Rectangular
        - Pulse repetition rate
        - Pulse duration

- Trapezoidal pulse train
    - Pulse repetition rate
    - Pulse duration
- Triangular risetime
    - Pulse repetition rate
    - Pulse deviation
- Sawtooth
    - Pulse repetition rate
    - Pulse duration
- Damped sinusoid
    - Pulse repetition rate
    - Oscillatory frequency of damped sinusoid
    - Decay frequency of damped sinusoid
    - Voice
    - Clipped voice
- Amplitude (volts, amps)
- Units code
- Bandwidth of information
- Electro-explosive device port
    - Adjustment limit
    - Maximum power for no fire
    - Maximum current for no fire
- Equipment Case Port
    - Spectrum adjustment limit displacement from initial spectrum level
    - Narrowband specification spectrum
    - Broadband specification spectrum

For all of the above port types the modulation/signal parameter may be specified as user input. That is, the user may specify up to ten frequency/amplitude point pairs to use in lieu of the prestored modulation models.

4.2 XM-1 System Definition

The XM-1 system is a main battle tank weapon operated by a four-man crew consisting of the commander, gunner, loader, and driver. The main weapon is a 105 mm cannon mounted on a 360-degree rotational turret. A 7.62 mm machinegun is mounted coaxially with the main gun. The commander's weapon station is also equipped with a .50 caliber machinegun mounted externally on the turret roof. The loader's weapon station is equipped with a circular skate mount to accommodate a 7.62 mm machinegun. The XM-1 system weights approximately 59 tons and is powered by an electronically controlled AGT-1500 turbine engine with hydrokinetic transmission.

Primary electrical power is provided by six 12-volt batteries arranged in a series parallel network to provide 24 volts for the system. The battery-charging network consists of an oil-cooled alternator and a solid state regulator. Electrical power distribution is accomplished through a two-wire-isolated return, electrical system. A separate power buss is maintained for isolation of sensitive control circuits. The power ground wire is routed with the corresponding hot wire in a twisted pair for EMC control. Use of EMI shielding on harnesses and electrical components is, at a minimum, in accordance with accepted EMC practices as established by handbooks on interference reduction for design engineers.[3,4] Communication is provided by an AN/VRC-12 radio and AN/VIC-1 intercom set with provisions for a voice security unit.

The fire control network is comprised of a solid state ballistic computer, crosswind sensor, line-of-sight data link transfer, laser rangefinder, main gun/turret drive stabilization, a thermal imaging system and gunner's primary sights.

In order to perform an IEMCAP analysis on the XM-1 (or any other system), it is necess y to provide certain input data (see Section 4.1) on the system. Using the applicable documents (see Appendix II), the XM-1 tank configuration was studied and analyzed and the critical systems were defined for use in the intrasystem analysis process. The various electronic subsystems in both the turret and hull portion of the XM-1 were identified and consists of the following:

- Receiver Transmitter - RT-246/VRC
- Auxiliary Receiver - R-442/VRC
- Intercommunication Amplifier - AM-1780/VRC

- Receiver Amplifier - AM-6748
- Ballistic Computer
- Crosswind Sensor
- Fire Extinguisher
- Line-of-Sight (LOS) Stabilization and Data Transfer Link
- Laser Range Finder (LRF)
- Main Weapon/Turret Drive Stabilization
- Thermal Imaging
- Gunner's Primary Sight
- Commander's Weapon Station Azimuth Drive

Other equipments and/or subsystems can be added to the above list as deemed appropriate.

The above subsystems were examined to determine the operationally required parameters, overall frequency ranges, susceptibility, physical layout of the equipment and the wire bundling (i.e., interconnecting cables between the various subsystems). It was determined that all of the above subsystems are required to meet the specifications of MIL-STD-461A (Notice 3 and/or Notice 4). Thus, the frequency ranges and susceptibility requirements can be defined for these subsystems using the MIL-STD-461A limits.

The operationally required parameters for the communication equipment can be obtained from the technical manuals associated with each equipment. Most of the operational parameters for the remainder of the XM-1 subsystems are not available in the documents discussed above. In particular, the parameters associated with the signal and control emission and reception characteristics of the XM-1 subsystems (e.g., Ballistic computer, crosswind sensors, etc.) are not available in the documents, but are required for input to the analysis process. Other documents will be required to obtain this data.

The interconnecting wiring for the XM-1 subsystem is available in the EMI control plan documents. The lengths of the wires, shielding and bundling data are specified. Other wire characteristics such as size, per unit length capacitance, loading, etc., are not specified in these documents and must be obtained from other sources.

4.3 Input Data Collection on XM-1 Tank

This section addresses the input data requirements for performing an EMC analysis on the XM-1 tank and the problems encountered in obtaining the data. The various XM-1 subsystems (see Section 4.2) were studied and the appropriate data needed for the analysis were determined. The availability of the data from several sources is presented.

4.3.1 Input Data Needed To Run IEMCAP

In order to be able to use the IEMCAP in the analysis of the XM-1 tank, there are certain input data requirements that must be satisfied. As discussed in Section 4.1, the system, subsystem, equipment and port data for the XM-1 tank must be established and the various parameters defining these elements must be specified. The system level data pertaining to the XM-1 includes:

- System Definition
- Antenna Data
- Filter Data
- Wire Characteristics Data
  - Unshielded
  - Single Shielded
  - Double Shielded

The system definition consists of picking the system type and its associated coordinate option such that meaningful results are obtained from the program. For the tank either a ground or aircraft system would be appropriate since there are only two antennas to be considered. Everything else would be located inside the structure (i.e. equipments wiring, etc.) and therefore would not have any detrimental effects on the outcome of the analysis. The antenna, filter and wire data are handled in a straight forward manner as defined for the IEMCAP.

The subsystem designations are arbitrary but at least one must be assigned to the XM-1.

For each equipment within the XM-1, the following data are required:

- Identification Code
- MIL-STD for Nonrequired Spectra

- Compartment Identification
- Position Coordinates
- Frequency

The equipment identification code should be unique to each equipment. One of the prestored MIL-STDS must be chosen for the nonrequired spectra. The MIL-STD may be adjusted to reflect a more or less stringent specification on a given equipment. Equipments located in the same compartment will be examined for case-to-case radiation problems. The position coordinates are used to determine separaticn distances between equipments and this distance is used in the case-to-case radiation problems. A set of frequencies must be defined for each equipment. These frequencies include both required and nonrequired frequencies for the various ports of an equipment. The XM-1 port input data for wire and antenna connector ports consists of port identification codes and the data requirements presented in Section 4.1.4.

Additional port specification input data includes the source and/or receptor data as a function of port type. The port types in the XM-1 includes radio frequency, power and signal and control. The port and corresponding source and receptor data identifies the characteristics of the modulation scheme, and completely describes the operational and nonoperational requirements of the system

4.3.2 Input Data Obtained From Available Documents

Using the available documents (see Appendix II), the operationally required parameters for the communications equipment can be obtained. The technical manual(TM) associated with a given system contains all of the operational data that is pertinent to the IEMCAP. TM's were available on the following equipment:

1) Receiver/Transmitter-RT-246/VRC,
2) Auxiliary Receiver-R-442/VRC,
3) Intercommunication Amplifier-AM-1780/VRC
4) Receiver Amplifier-AM-6748

The interconnecting wiring for the XM-1 subsystems can be obtained from the EMI control plan documents. However, the EMI control plan documents may or may not represent the actual wiring configuration in a production model of the XM-1.

Overall, the data that was available on the XM-1 through documentation was very limited. Technical Manuals on most of the XM-1 subsystems were not available during this effort. Several TM's were obtained on "Direct Support and General Support Maintenance Manuals" pertaining to both the hull and turret portions of the tank. These manuals provide information necessary to troubleshoot each assembly or line replaceable units of the XM-1 but, they do not contain the type of data required by the IEMCAP.

4.3.3 Input Data From Other Sources

To obtain the remaining data needed to perform the IEMCAP analysis of the XM-1 tank, a request was made to cognizant Army personnel. This request contained four areas for which additional data was required to perform the XM-1 analysis.

In order to perform the analysis, additional data was needed in the following areas:

- Physical layout of equipments
- Required operating characteristics for the signal and control functions of each subsystem
- Nonrequired emission and susceptibility characteristics
- Wire characteristics and routing (bundles)

For IEMCAP purposes, the physical layout of the equipments within the system to be analyzed must be specified. The physical boxes comprising a

subsystem are defined as equipments. The location of the equipment within the system is determined by specifying the coordinates (x, y, z) of the center of the physical box representing the equipment. The units for the equipment coordinates may be specified in any convenient manner. However, for input to the IEMCAP the equipment coordinates should be specified in "inches."

The required operating characteristics for the signal and control function of each subsystem are handled by IEMCAP via ports. Electromagnetic (EM) energy may enter or leave equipments in a subsystem through ports. Ports are designated as emitters (i.e., the emission of EM energy) or receptors (i.e., the reception of EM energy) or both. Thus, an emitter port generates EM energy and a receptor port is susceptible to EM energy. For the signal and control functions of an equipment, the ports are represented by the connector pins through which the signals enter or leave the equipment. Such ports are connected to wires and the specific data required for each port is presented in Section 4.1.4.

The signal and control port data requirements were required for the following XM-1 tank electronic subsystems:

- Ballistic Computer
- Crosswind Sensor
- Fire Extinguisher
- Line-of-Sight (LOS) Stabilization and Data Transfer Link
- Laser Range Finder (LRF)
- Main Weapon/Turret Drive Stabilization
- Thermal Imaging
- Gunner's Primary Sight
- Commander's Weapon Station Azimuth Drive.

In performing the intrasystem EMC analysis on the XM-1 tank, the port's nonrequired emission and susceptibility characteristics must be specified. The nonrequired characteristics are those responses which are not instrumental in the performance of the designed function for the port. For IEMCAP purposes, the appropriate MIL-STD-461A specification may be used. Since the XM-1 tank electronic subsystems are required to meet MIL-STD-461A specifications, it seems appropriate to use these specs for the nonrequired emission and susceptibility requirements. It was suggested that if other documents were available which contained pertinent data or additional guidelines on the frequency response of the XM-1 electronic subsystems, then these data should be included in the analysis.

The interconnecting wiring for the XM-1 subsystems listed above is available in the EMI control plan documents. The lengths of the wires, shielding and bundling data are specified. Other wire characteristics such as size, per unit length capacitance, loading, etc., are not specified in these documents and must be obtained from other sources. For the IEMCAP, the wire characteristics required for the various types of wires is defined in Section 4.1.4.

In addition to the above wire characteristics, any filters in the wiring between the XM-1 tank subsystems must be defined. The filter model parameters are a function of the prestored models. The prestored filter models consist of a single tuned stage, transformer coupled stage, Butterworth tuned, lowpass, highpass, bandpass and band reject. The required input data for each filter model is defined in Section 4.1.1.

Using the above data request, Army personnel requested (through proper channels) these data from the Chrysler Corporation, the XM-1 tank's developer and builder. Chrysler agreed to provide this data but at at very high cost. Army personnel then determined that it was not cost effective to obtain the required data from the tank's developer for performing an IEMCAP analysis on the XM-1 tank.

Other sources that were pursued to obtain the data included other documentation (see Section 4.3.2) associated with the various equipments that were available and an on site visit to an actual XM-1 tank. Army personnel were unable to find an available XM-1 tank for a visual on sight inspection and data collection.

4.4 Results of Analysis

This section presents a discussion of the attempt to perform an EMC analysis on the XM-1 tank. The IEMCAP was not used to perform an EMC analysis on the XM-1 tank because the required data needed to run the program could not be obtained in a manner that was cost effective (See Section 4.3). Based on the experience gained in trying to obtain the data on the XM-1 it would appear that the Army will have to take the necessary steps to alleviate this problem in the future. For new systems, like the XM-1, it may be cost effective to require a CDRL item to ensure that the data (on an as available basis) will be provided for analysis purposes. Once a system becomes operational, a cost effective method is needed for assuring that the data required for analyzing the system has been properly documented.

In any analysis process or method, there will always be a need for a certain amount of data in order to provide meaningful results. As a part of the XM-1 analysis, a task was performed to determine the minimum data set required by IEMCAP to perform an EMC analysis on the XM-1 tank. The data requirements established for the XM-1 were made based on our knowledge of the IEMCAP, EMC background in analysis techniques and some conclusive results obtained by exercising the IEMCAP code (see Section 5.0). The IEMCAP minimum data requirements for analyzing the XM-1 or any other similar system consists of the following:

1) Antennas:

    All parameters listed in Section 4.1.1.

2) Filters:

    All parameters listed in Section 4.1.1.

3) Wires:

    - Types

      All types listed in Section 4.1.1.

    - Characteristics
        - Unshielded wires
        - Unshielded diameter
        - Insulation thickness
        - Twisted pair or single wire
        - Single shielded wires

          All parameters listed in Section 4.1.1.

- Double shielded wires
  - conductor diameter
  - conductor conductivity
  - insulation thickness
  - insulation dielectric constant
  - inner shield internal diameter
  - inner shield thickness
  - inner shield jacket thickness
  - shield-to-conductor capacitance (to inner shield)
  - outer shield thickness
- Wire connected port
  - bundle point identification
  - return path of signal
  - shield termination
  - termination resistance
- Antenna connected port
  - vertical angle of mainbeam peak
  - azimuth angle of mainbeam peak
  - antenna coordinates
  - termination resistance

4) <u>Ports</u>:

- Types
  - radio frequency
  - power
  - signal
  - control
  - electro-explosive devices
  - equipment case
- Characteristics
  - radio frequency port

  All parameters listed in Section 4.1.4.

- Power port
  - voltage (RMS) of line
  - frequency (0 if DC)
  - highest harmonic
  - number of phases
  - ripple or noise spectrum
- Signal and control ports
  - lowest required frequency
  - highest required frequency
  - modulation/signal code

    All parameters listed in Section 4.1.4.

All of the above data is required by the IEMCAP in order to get meaningful results in an analysis. However, the wire characteristics and wire bundling data may be input in such a manner as to ensure that the results are an over prediction (worst case) and then certain rules of thumb may be used to ascertain coupling limits for a particular problem. That is, if certain wire characteristics are not known to a high degree of accuracy, an analysis using IEMCAP may still be performed to obtain reasonable results. For example, if the spacing between wires is an unknown quantity, one could input the data in IEMCAP such that the minimum separation (touching case) between the wires is used in the coupling calculations. The minimum wire separation leads to the maximum possible coupling and thus to the worst case interference condition. Knowing the maximum possible coupling, the rules in Section 5.2 may be applied to determine the range of coupling for varying wire separations.

5.0 IEMCAP INPUT DATA SENSITIVITY ANALYSIS

A sensitivity analysis was performed on IEMCAP input parameters for the purpose of gaining insight into the effects of approximating the input parameters on IEMCAP predictions. The sensitivity study was crucial in determining what data is needed to perform an IEMCAP analysis of the XM-1 and other Army systems. Portions of the analysis are based on our IEMCAP expertise and results existing in the open literature. For wire data, the wire-to-wire portion of the IEMCAP (version 04) was extracted from the code and a stand alone code developed and exercised to obtain wire and wire bundling sensitivity data.

5.1 REQUIRED INPUT DATA

There are associated with the IEMCAP certain input parameters that determine whether or not useful predictions can be made. For the XM-1, these parameters are defined at the system, equipment and/or the port level of the hierarchical data structure. At the systems level the antennas, filters and wire characteristics must be established and defined. Each of these elements are specified by a set of common parameters that can be used as required at the various ports throughout the system. These parameters are defined in Section 4.1 and the minimum data sets are presented in Section 4.4. The IEMCAP outputs are very sensitive to the definition of the system level elements.

The equipment data that must be defined includes location of the equipment, a MIL-STD specification and the equipment frequency table. Each of these data can have a significant impact on the output results for IEMCAP. The integrated margin is especially sensitive to the choice of frequency components that are defined for an equipment.

The port data that must be specified for IEMCAP is a function of the port type. However, for all port types the important parameters consist of carrier frequency limits, and/or other required frequency limits, power output for emitters, minimum sensitivity for receptors, modulation characteristics and termination resistance. The frequency limits of a port will have a definite impact on the interference margin calculations. There is no nominal or average modulation characteristics that may be input for a port.

The defined parameters for a modulation scheme associated with the port have to be known for performing an IEMCAP analysis. A port termination resistance definitely effects both the wire-to-wire and antenna-to-antenna type coupling problems. Port termination may produce errors on the order of several dB in the coupling calculations alone.

5.2 WIRE DATA SENSITIVITY ANALYSIS

In this section, results of sensitivity analysis calculations are presented and discussed. The results are given in the form of plots of wire-to-wire coupling as a function of frequency as a parameter is varied.

The wire-to-wire coupling calculations and corresponding graphs (in negative dB) represent a current transfer ratio (in dB) between an emitter wire and a receptor wire.

A set of guidelines is recommended for modifying a coupling calculation in the case that a parameter is not accurately known. The results are presented and discussed in Section 5.2.1 and the discussion and recommendations are given in Section 5.2.2.

5.2.1 Sensitivity Analysis: Calculations and Results

The sizable amount of data required for the wire-to-wire coupling analysis program makes a complete sensitivity analysis a major undertaking. The sensitivity analysis performed here is more modest in scope and is intended as an investigation of some of the more important parameters. Five wire configurations were examined:

- Both wires unshielded
- Emitter wire unshielded; receptor wire single shielded
- Emitter wire single shielded; receptor wire unshielded
- Both wires single shielded
- Emitter wire unshielded; receptor wire double shielded

For each configuration, several parameters are varied separately and the resulting variations in coupling plotted as a function of frequency. The frequency range was chosen to be from 100 kHz to 100 MHz. From each plot, a guideline is deduced which estimates the change in wire-to-wire coupling to be expected due to a change in the wire parameter. These guidelines allow the user to approximately estimate the effect on the wire-to-wire coupling of overestimating or underestimating a wire parameter. This is important for the calculation of wire-to-wire coupling in systems whose parameters are not precisely known. The results for the five wire configurations analyzed are discussed in Sections 5.2.1.1 - 5.2.1.5.

5.2.1.1 Both Wires Unshielded

The first wire configuration analyzed was the case of both wires unshielded. The baseline characteristics of each wire is given in Table 5.1. These wire characteristics were chosen b..sed on Dr. Paul's[2] work. By using these parameters, a base line was established between previous wire-to-wire coupling work and the work presented herein. The unshielded wire is a #20 gauge solid wire with polyvinylchloride insulation. The single shielded wire is comparable in size to the #20 gauge wire. The double shielded wire is RG-55/U cable. Four separate sensitivity calculations were performed:

- Variation of average wire separation
- Variation of wire bundle segment height
- Variation of wire bundle segment length
- Variation of segment length, height and wire separation simultaneously.

The results are plotted in Figures 5.1a - 5.1d and the guidelines are given in Table 5.3. The guidelines indicate how a wire-to-wire coupling calculation may be modified or corrected due to variations in a parameter or parameters. The coupling corrections were chosen for "Worst Case" which is consistent with the philosophy of the IEMCAP. The $\pm$100% variation corresponds to a 100% overestimate of underestimate, respectively, of the true parameter magnitude. In such a case, the coupling curve will increase (+) or decrease (-) a certain number of dB in a given frequency range. For example, in Figure 5.1a the coupling at 1.0 MHz with a wire separation of 0.65 cm is -24 dB. A +100% increase in the wire separation (1.3 cm) at this frequency results in a -29.3 dB coupling. Thus, a doubling of the wire separation results in a net change in the coupling of -5.3 dB. Different corrections are possible for different frequency ranges. Smaller or larger variation increments produce proportional coupling corrections. Note that an overestimate (+) of a parameter does not necessarily lead to an overestimate (+) of the coupling. It could lead to an underestimate (-). In a similar manner an underestimate (-) of a parameter could lead to an overestimate (+) of the coupling.

For variations in average wire separation, a 12-foot segment 0.012 meters above the ground plane was used. From Figure 5.1a, as the separation increases, the coupling decreases rather uniformly over the frequency band. From Table 5.2, a 12-foot wire can be considered electrically short (less than 0.1 wavelength) for frequencies up to 16 MHz. The coupling curves should be considered valid only up to this frequency. Agreement beyond this frequency is possible but is less likely. All wire separations considered here are electrically small.

Table 5.1 Baseline Physical and Electrical Parameters for Wires

Parameter[a,b]	Unshielded	Single Shield	Double Shield
Conductor diameter	31.96	31.0	32
Conductivity (Relative to Copper)	1	1	1
Insulation thickness (outer radius-inner radius)	16	9	42
Dielectric constant (Relative to Free Space)	3.5	3.5	2.3
Inner shield internal diameter	-	49	116
Inner shield thickness	-	15.5	20
Inner shield jacket thickness	-	5	5
Shield-to-conductor capacitance	-	129.55	28.5
Outer shield internal diameter	-	-	156
Outer shield thickness	-	-	20
Segment length (ft.)	12	12	12
Segment height above ground (cm)	1.4	1.4	1.4
Average wire separation (cm)	just touching	just touching	just touching
Terminating port resistance (ohms)	50	50	50

a. All distances, unless otherwise noted, are in mils

b. Capacitance is in pf/ft

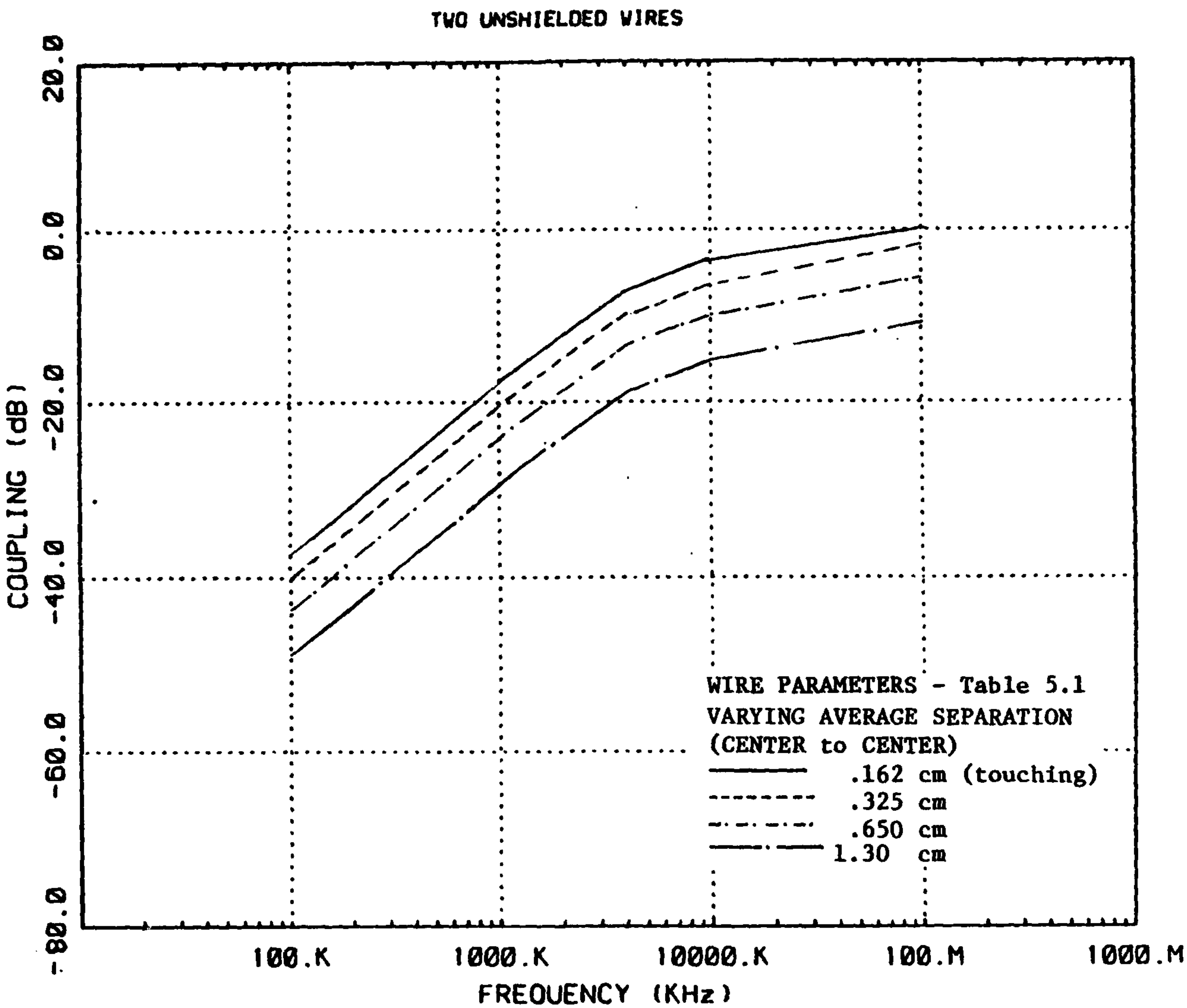

TWO UNSHIELDED WIRES
20.0
0.0
-20.0
-40.0
-60.0
-80.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING AVERAGE SEPARATION
(CENTER to CENTER)
.162 cm (touching)
.325 cm
.650 cm
1.30 cm

Figure 5.1a

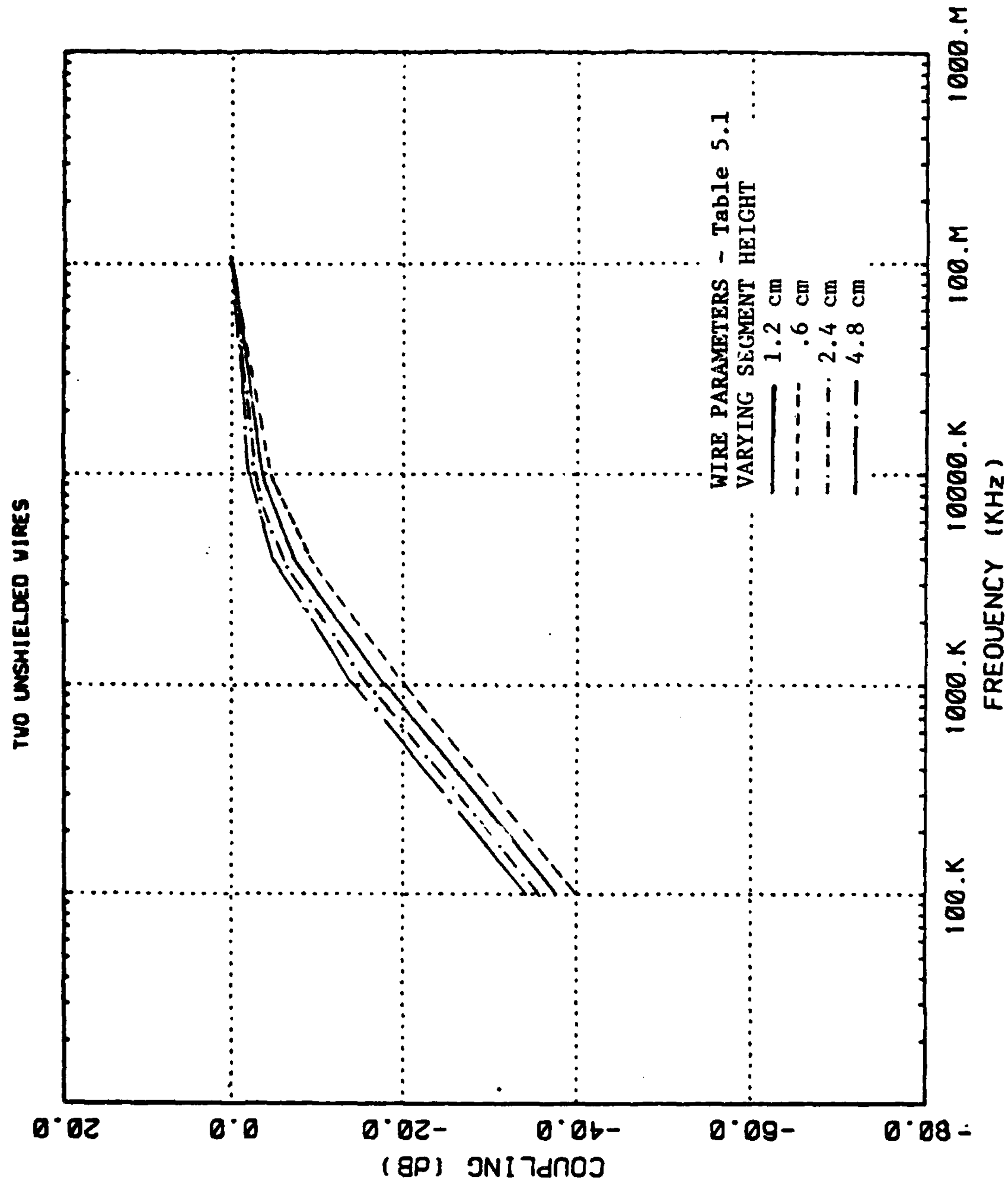
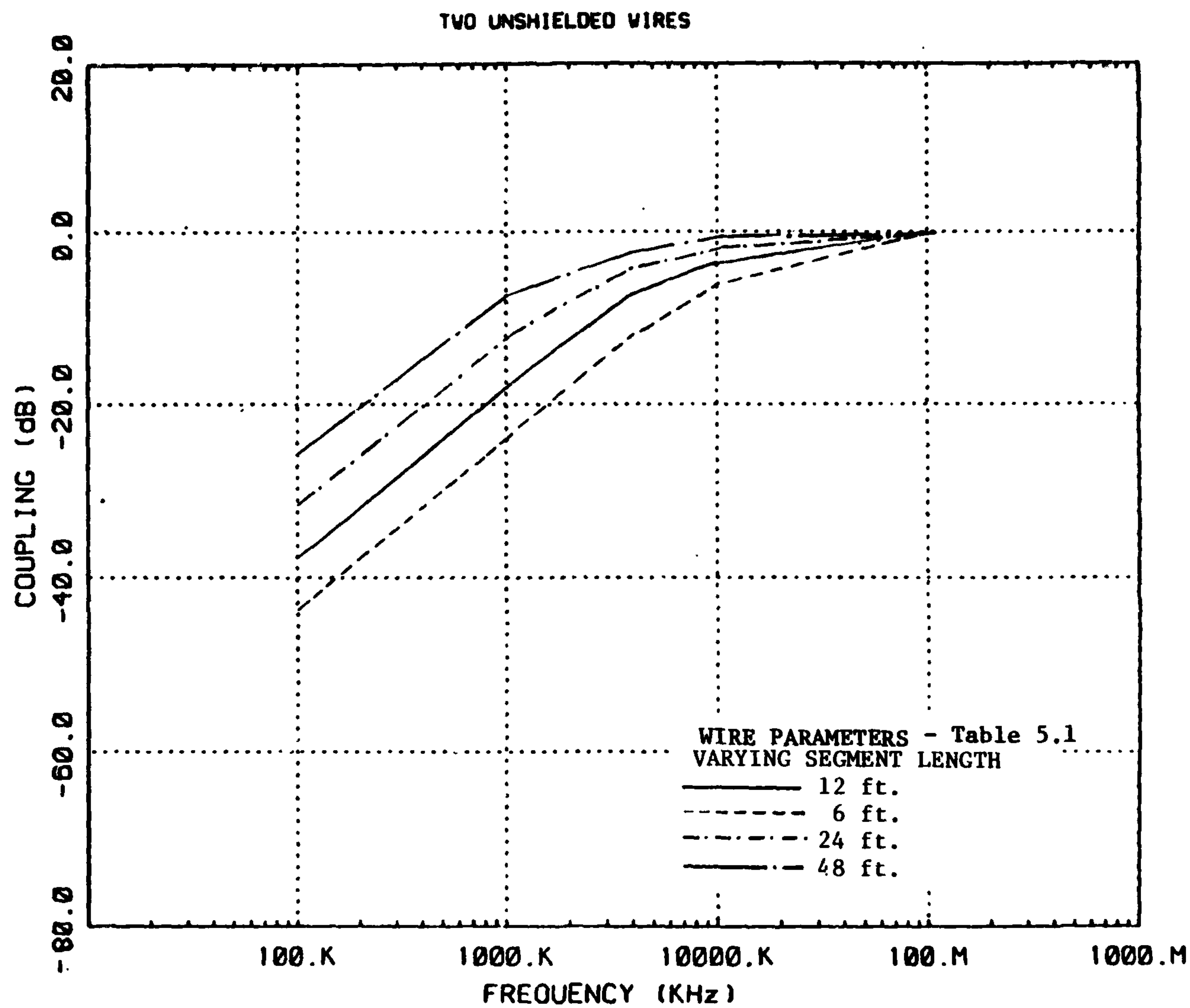

TWO UNSHIELDED WIRES
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT HEIGHT
1.2 cm
.6 cm
2.4 cm
4.8 cm
COUPLING (dB)
20.0
0.0
-20.0
-40.0
-60.0
-80.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.1b



TWO UNSHIELDED WIRES
20.0
0.0
-20.0
-40.0
-60.0
-80.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT LENGTH
12 ft.
6 ft.
24 ft.
48 ft.

Figure 5.1c

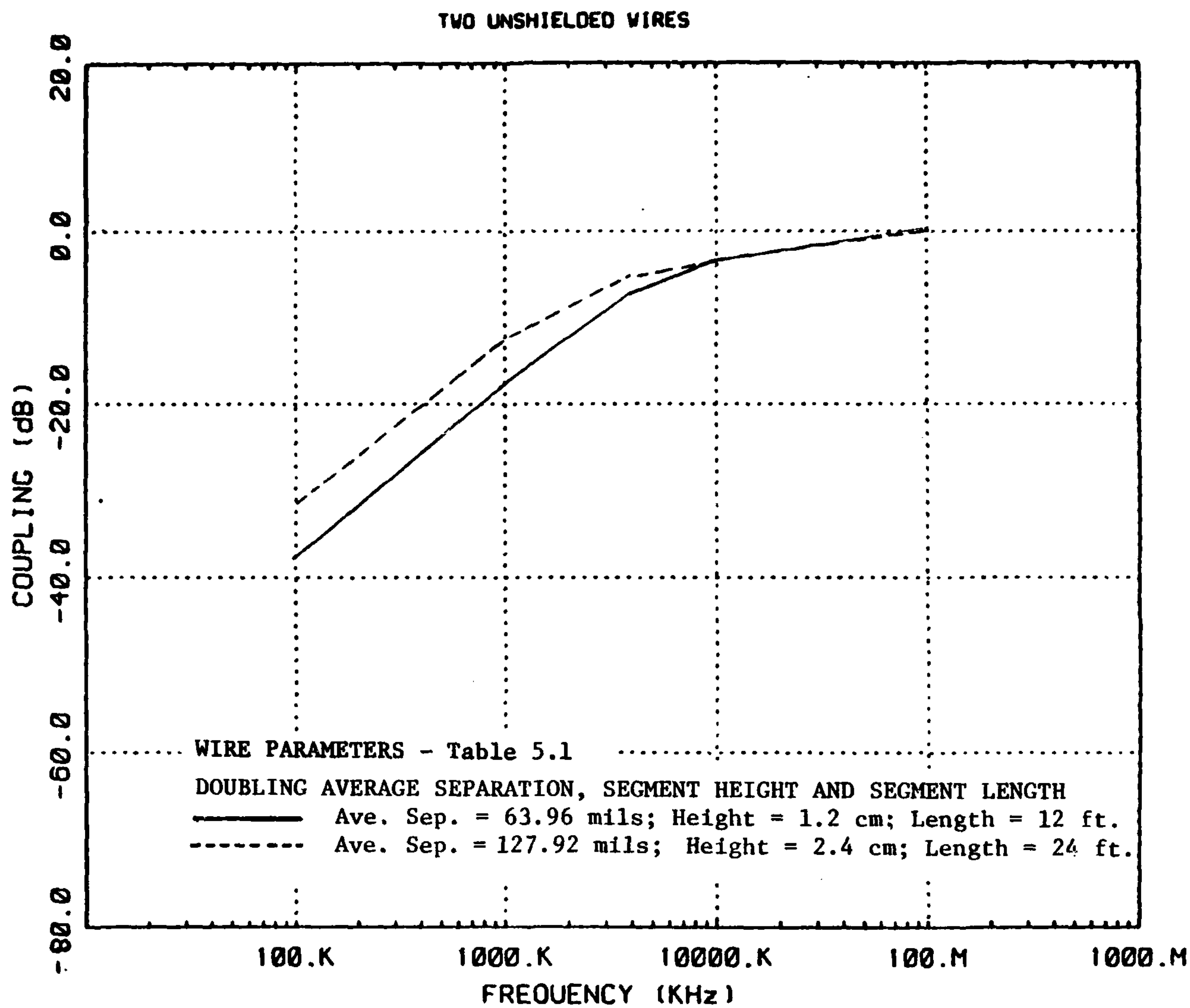

TWO UNSHIELDED WIRES
20.0
0.0
-20.0
-40.0
-60.0
-80.0
COUPLING (dB)
WIRE PARAMETERS - Table 5.1
DOUBLING AVERAGE SEPARATION, SEGMENT HEIGHT AND SEGMENT LENGTH
Ave. Sep. = 63.96 mils; Height = 1.2 cm; Length = 12 ft.
Ave. Sep. = 127.92 mils; Height = 2.4 cm; Length = 24 ft.
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.1d

Table 5.2 Wire Electrical Lengths

Frequency	Length of Wire (feet)			
	6	12	24	48
100 kHz	$.61 \times 10^{-3}$	1.22×10^{-3}	2.44×10^{-3}	4.88×10^{-3}
1 MHz	$.61 \times 10^{-2}$	1.22×10^{-2}	2.44×10^{-2}	4.88×10^{-2}
10 MHz	$.61 \times 10^{-1}$	1.22×10^{-1}	2.44×10^{-1}	4.88×10^{-1}
100 MHz	.61	1.22	2.44	4.88

The maximum separation between any two curves in Figure 5.1a is approximately 5.5 dB. Thus, a coupling correction factor of 5.5 dB is appropriate for the entire frequency range as shown in Table 5.3. This factor provides a "worst case" estimate for wire separations that are on the order of a factor of two (±100%). As shown by the figure, wire separations greater or less than a factor of two maybe determined by taking a percentage of the ±100% correction factor, e.g., a factor of 4 would be equal to 2x5.5 dB = 11 dB, etc.

The variation of the wire bundle segment above a ground plane also involves a 12-foot bundle. All segment height variations are electrically small and the wires in the bundle are electrically short for frequencies up to 16 MHz. As the segment height above the ground plane increases, the coupling also increases.

The coupling associated with a variation of segment height above a ground plane as shown in Figure 5.1b shows a converging trend with increasing frequency. The maximum separation between any two curves in the frequency range of 100 kHz to 16 MHz is approximately 2.5 dB. Between 16 MHz and 100 MHz the maximum spread is on the order of 1 dB. Thus, as shown in Table 5.3 these factors provide an estimate for determining the coupling correction associated with segment height above a ground plane. As shown by Figure 5.1b, the variation in segment height coupling maybe determined by taking multiples of the ±100% (factor of two) coupling correction as specified in Table 5.3. For example, the coupling correction for a factor of four change in height above a ground plane would be equal to 2 x 2.5 dB or 5 dB in the frequency range of 100 KHz to 16 MHz.

Variations in segment length range from 6 feet to 48 feet. From Table 5.2 all wires from 6 feet to 48 feet are electrically short for frequencies up to 2 MHz. Much beyond 2 MHz and the guidelines developed become unreliable due to the presence of resonance effects on electrically long lines. As the wire length increases, the coupling also increases. An analysis of the variation of wire length in Figure 5.1c was performed similar to that presented for the wire separation and segment height and the results are shown in Table 5.3.

Table 5.3 Coupling Guidelines for Both Wires Unshielded

Parameter Varied	Variation Increment[b]	Coupling Correction (dB)[c]
Average Wire Separation	$\pm$ 100%	$\pm$ 5.5 (100 kHz - 100 MHz)
Segment Height	$\pm$ 100%	$\mp$ 2.5 (100 kHz - 16 MHz) $< \mp$ 1.0 (16 MHz - 100 MHz)[a]
Segment Length	$\pm$ 100%	$\mp$ 6 (100 kHz - 2 MHz) $\mp$ 2 (2 MHz - 100 MHz)[a]
Segment Length, Height Wire separation	$\pm$ 100% for all parameters	$\mp$ 5 (100 kHz - 4 MHz) $< \mp$ 1 (4 MHz - 100 MHz)[a]

a. Validity of coupling curves questionable in this frequency range.

b. A plus (+) sign indicates overestimate of parameter; a minus (-) sign, underestimate.

c. The sign on the correction is correlated with the sign on the increment.

A final calculation was done for unshielded wires that involved increasing segment length, height and wire separation each by 100%. The wire lengths were 12 feet and 24 feet, respectively, and are electrically short up to about 4 MHz. All other variations are electrically small. The coupling increased with increased parameter size except at high frequencies where little variation was noted.

5.2.1.2 Unshielded Emitter Wire to a Single Shielded Receptor Wire

The second wire configuration that was analyzed consisted of an unshielded emitter wire and a single shielded receptor wire. The baseline characteristics of each wire are given in Table 5.1. Three shield grounding configurations were analyzed with this configuration:

- ungrounded
- single end grounded
- double end grounded.

Within each configuration, four different sensitivity calculations were performed:

- variation of average wire separation
- variation of bundle segment height
- variation of bundle segment length
- variation of reference wire return path (ungrounded configuration only)

The calculated results are plotted in Figures 5.2.1a - 5.2.3c as a function of frequency. The recommended guidelines are given in Table 5.4.

The discussion concerning the variation of segment length, segment height and wire separation is similar to the discussion given in Section 5.2.1.1 for unshielded wires although the guidelines are somewhat different. The different grounding configurations made little difference in the guidelines and served mainly to shift the relative positions of the graph. The different wire return paths (Figure 5.2.1d) made practically no difference and was considered to require no coupling correction in the guidelines.

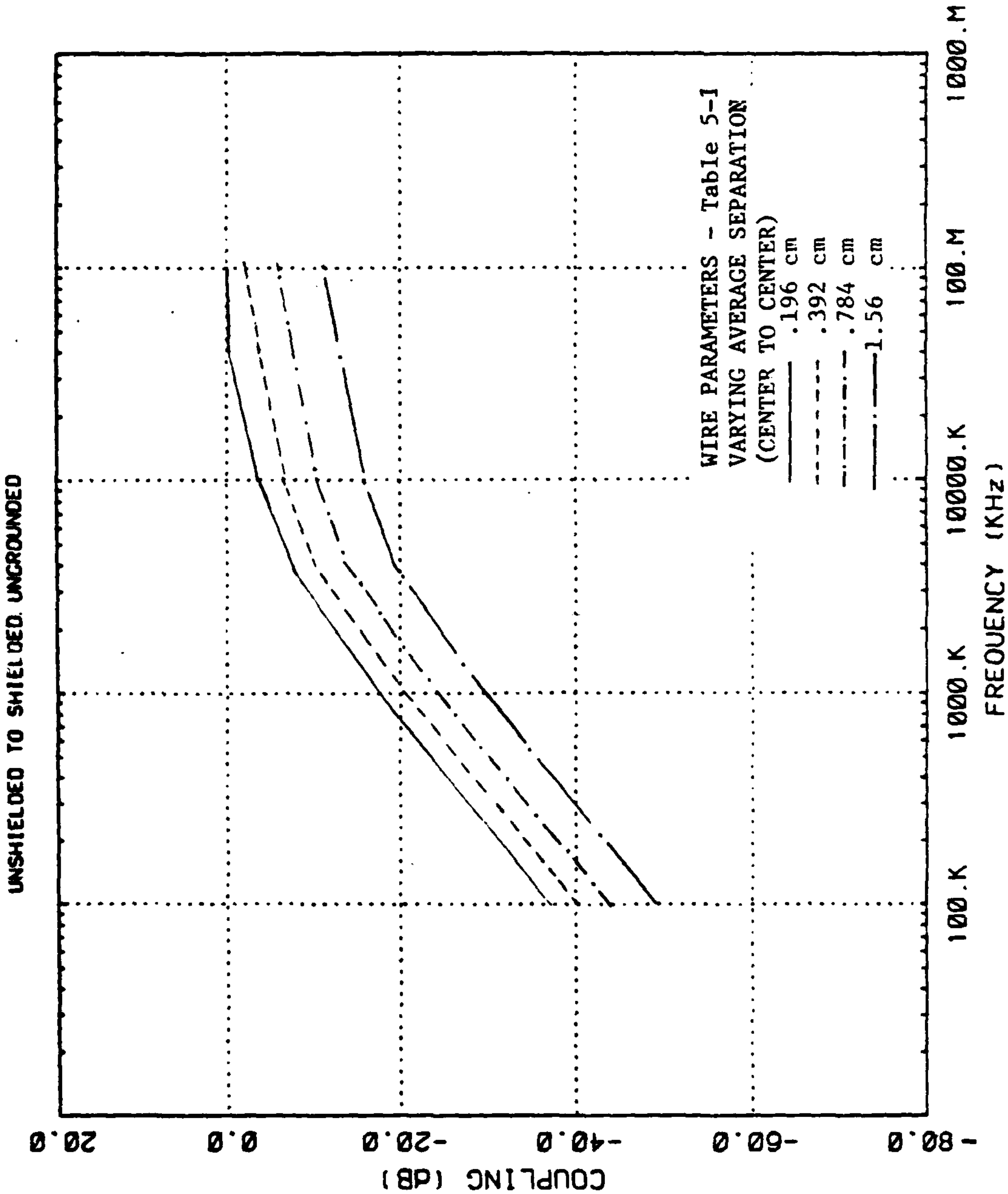

UNSHIELDED TO SHIELDED UNGROUNDED
COUPLING (dB)
20.0
0.0
-20.0
-40.0
-60.0
-80.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5-1
VARYING AVERAGE SEPARATION
(CENTER TO CENTER)
.196 cm
.392 cm
.784 cm
1.56 cm

Figure 5.2.1a

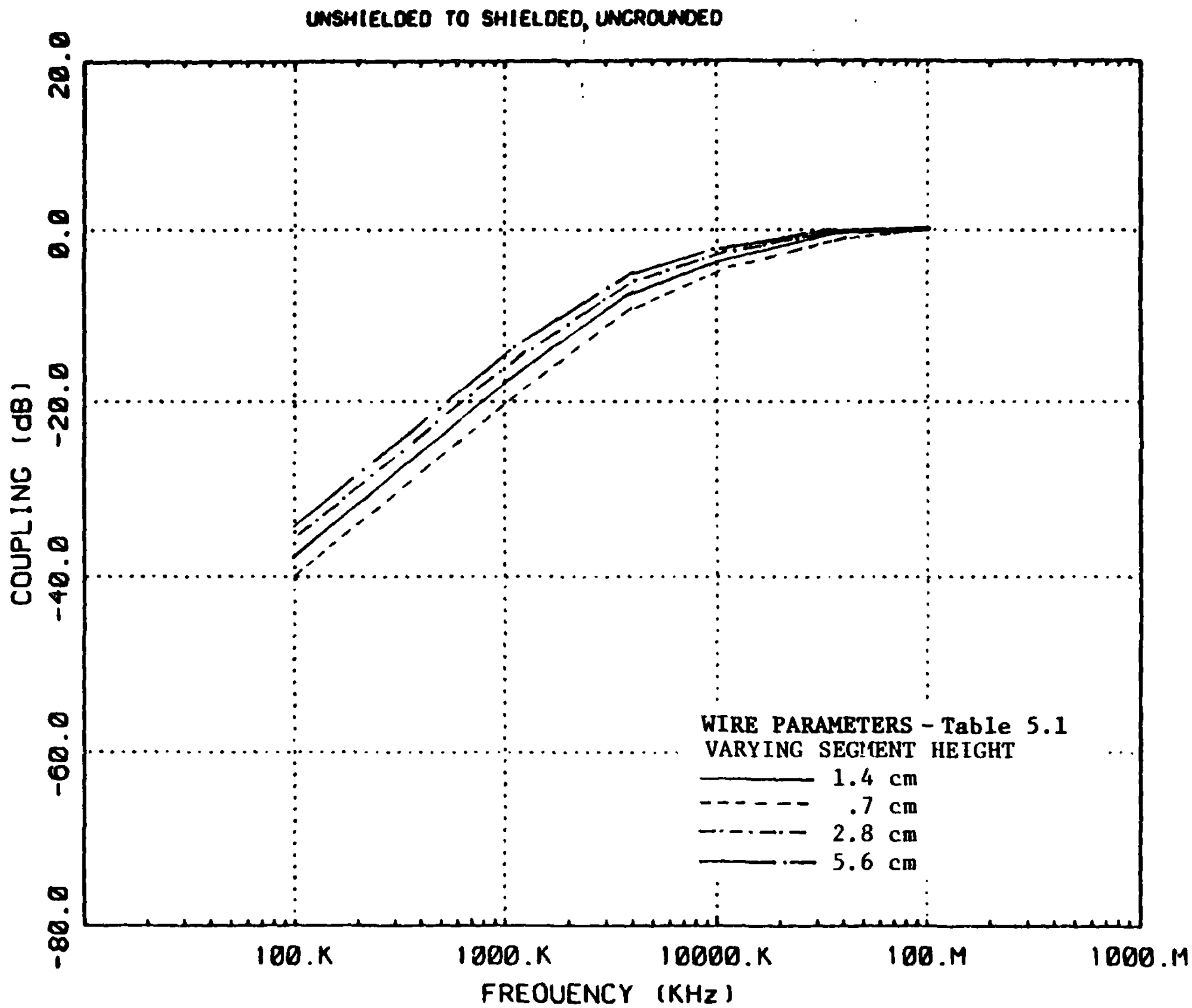
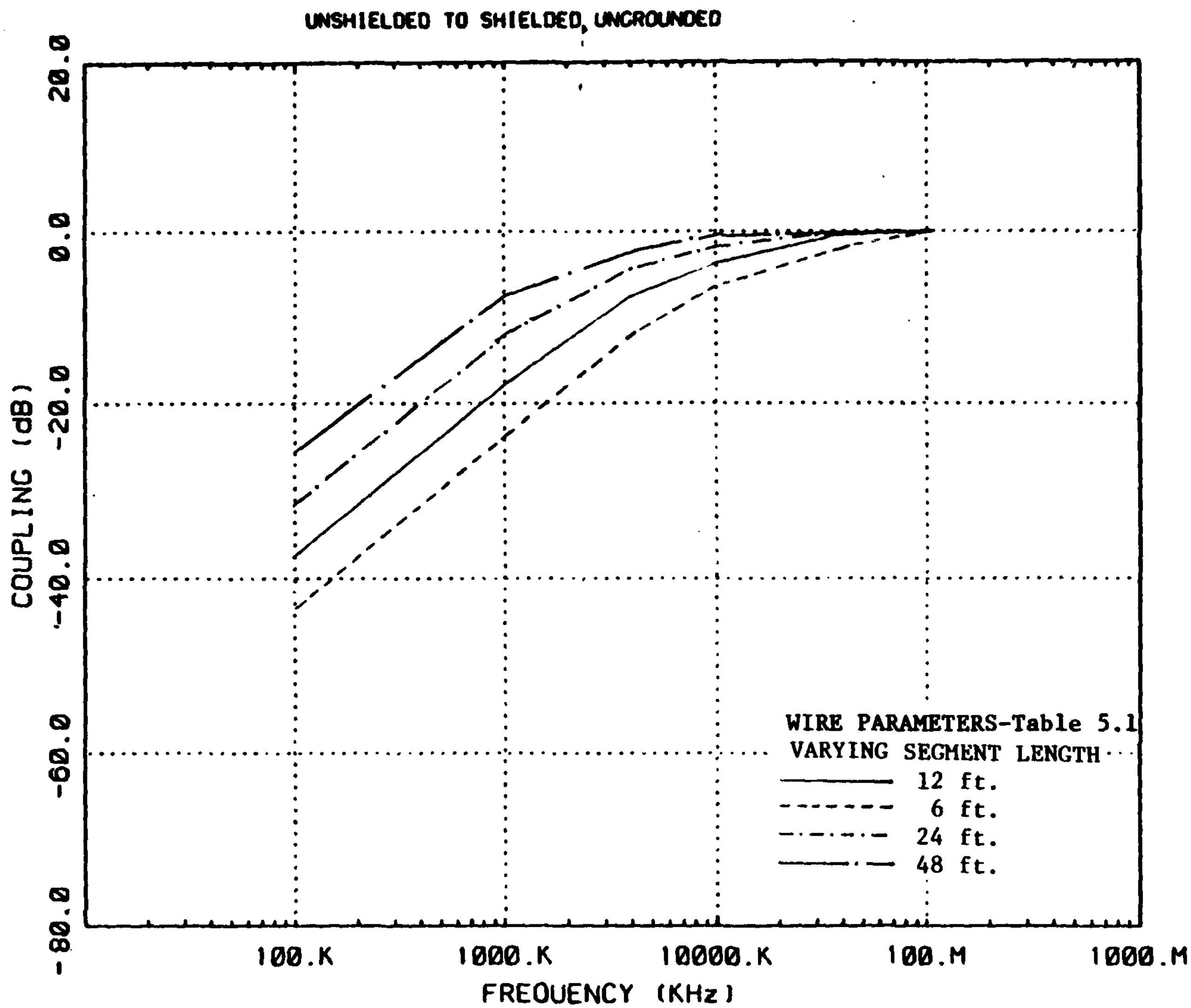

UNSHIELDED TO SHIELDED, UNGROUNDED
20.0
0.0
-20.0
-40.0
-60.0
-80.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT HEIGHT
1.4 cm
.7 cm
2.8 cm
5.6 cm

Figure 5.2.1b



UNSHIELDED TO SHIELDED, UNGROUNDED
COUPLING (dB)
20.0
0.0
-20.0
-40.0
-60.0
-80.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 ft.
6 ft.
24 ft.
48 ft.

Figure 5.2.1c

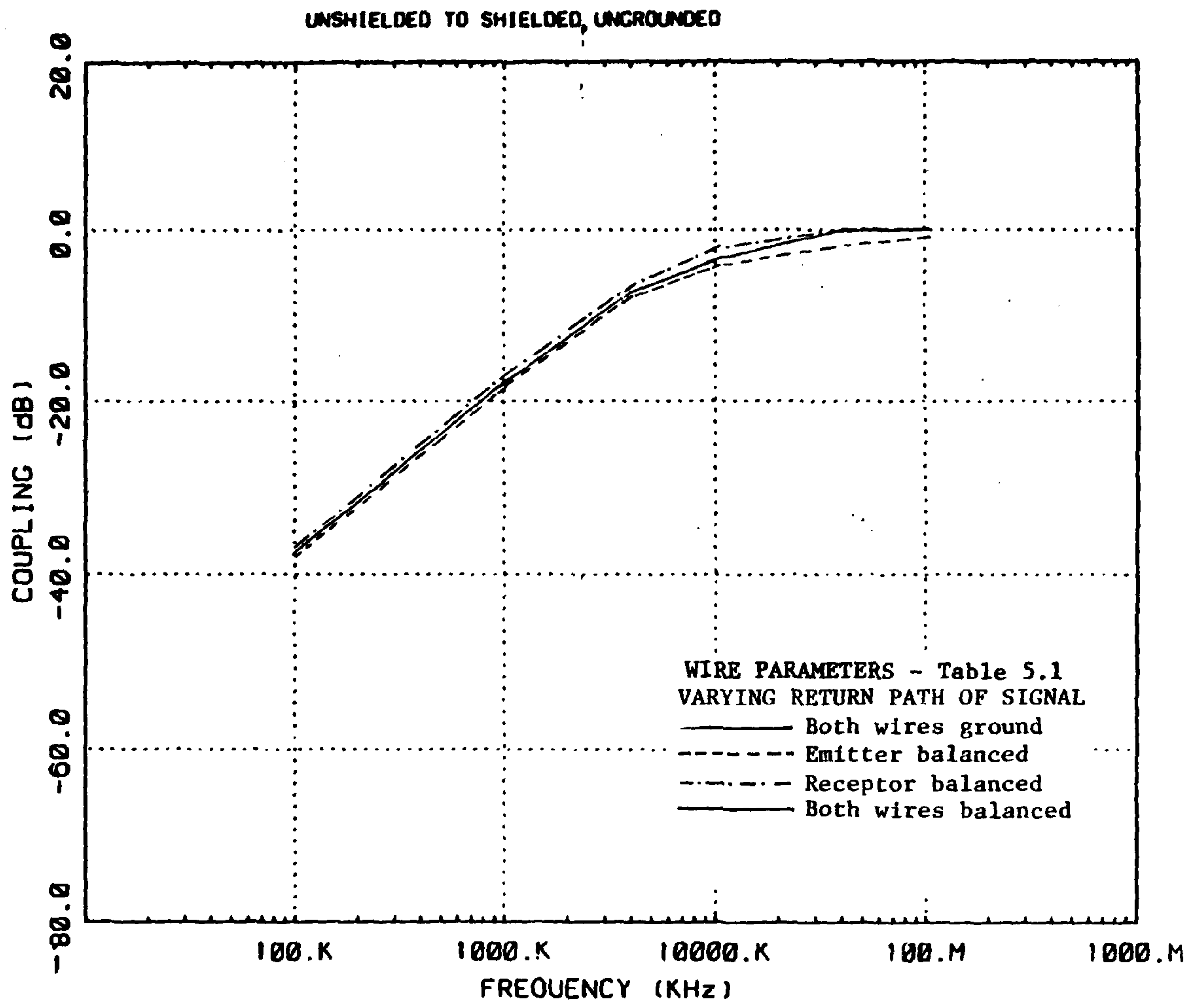

UNSHIELDED TO SHIELDED, UNGROUNDED
20.0
0.0
-20.0
-40.0
-60.0
-80.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING RETURN PATH OF SIGNAL
Both wires ground
Emitter balanced
Receptor balanced
Both wires balanced

Figure 5.2.1d

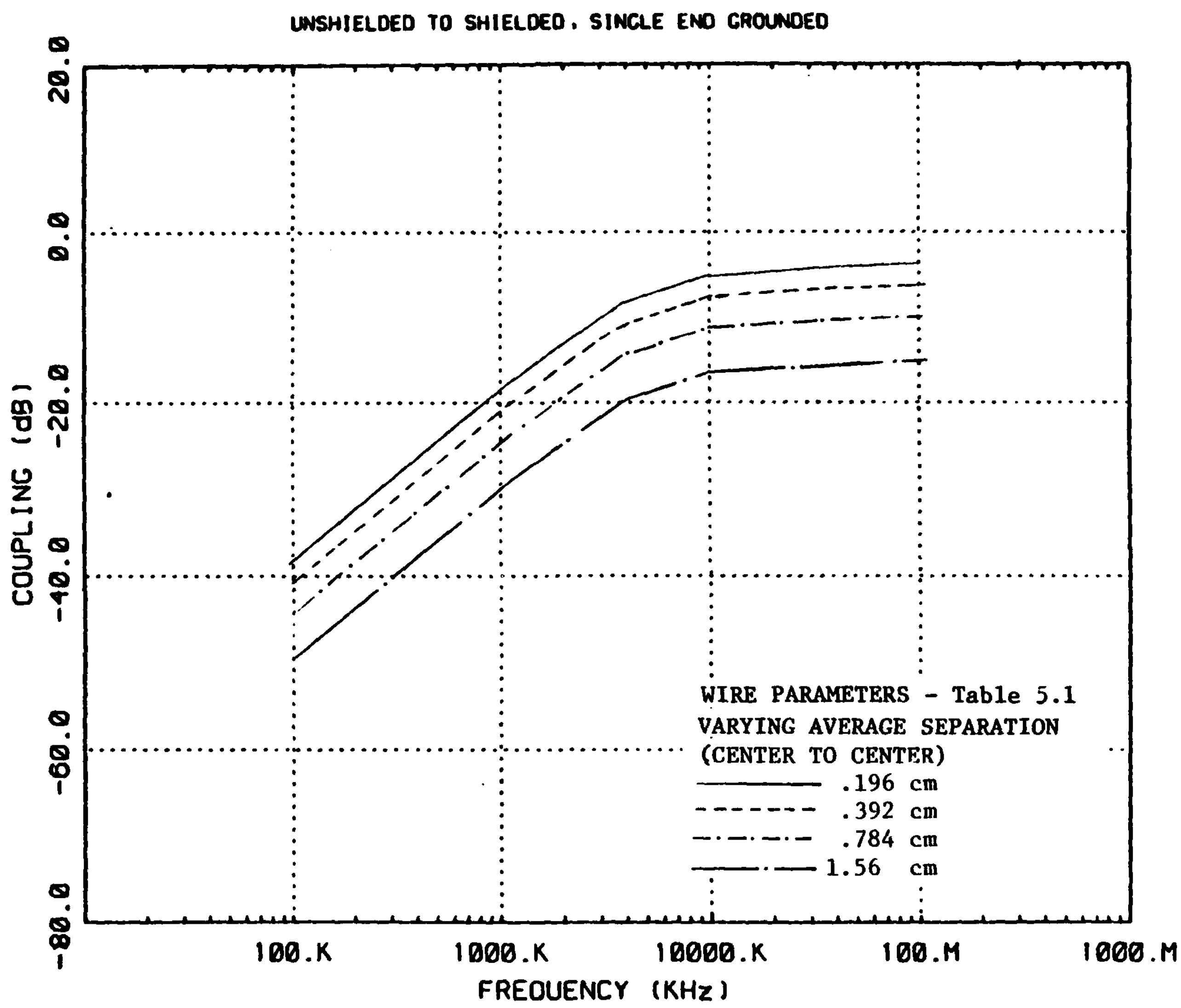
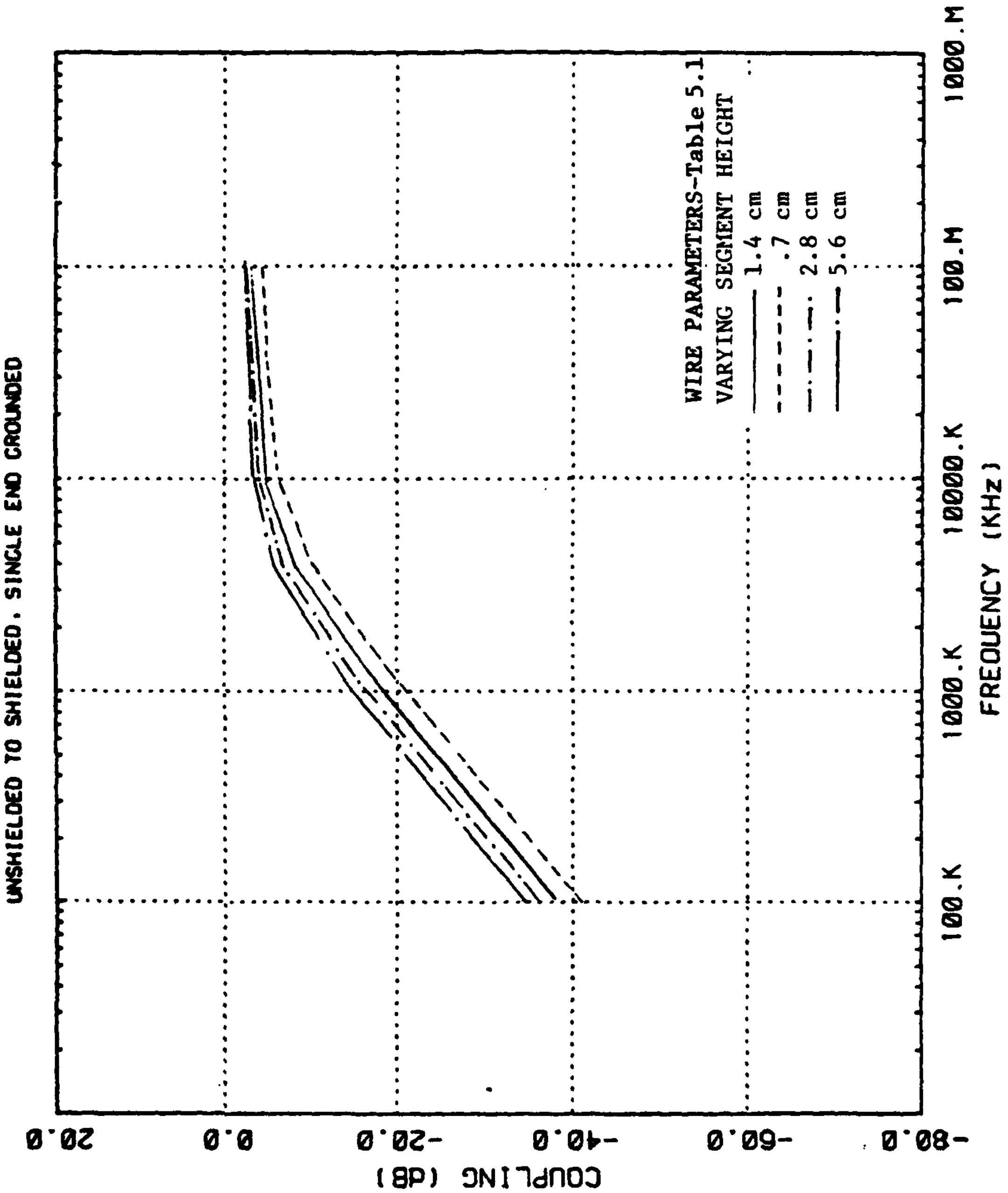

UNSHIELDED TO SHIELDED, SINGLE END GROUNDED
20.0
0.0
-20.0
-40.0
-60.0
-80.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING AVERAGE SEPARATION
(CENTER TO CENTER)
.196 cm
.392 cm
.784 cm
1.56 cm

Figure 5.2.2a



UNSHIELDED TO SHIELDED, SINGLE END GROUNDED
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT HEIGHT
1.4 cm
.7 cm
2.8 cm
5.6 cm
COUPLING (dB)
20.0
0.0
-20.0
-40.0
-60.0
-80.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.2.2b

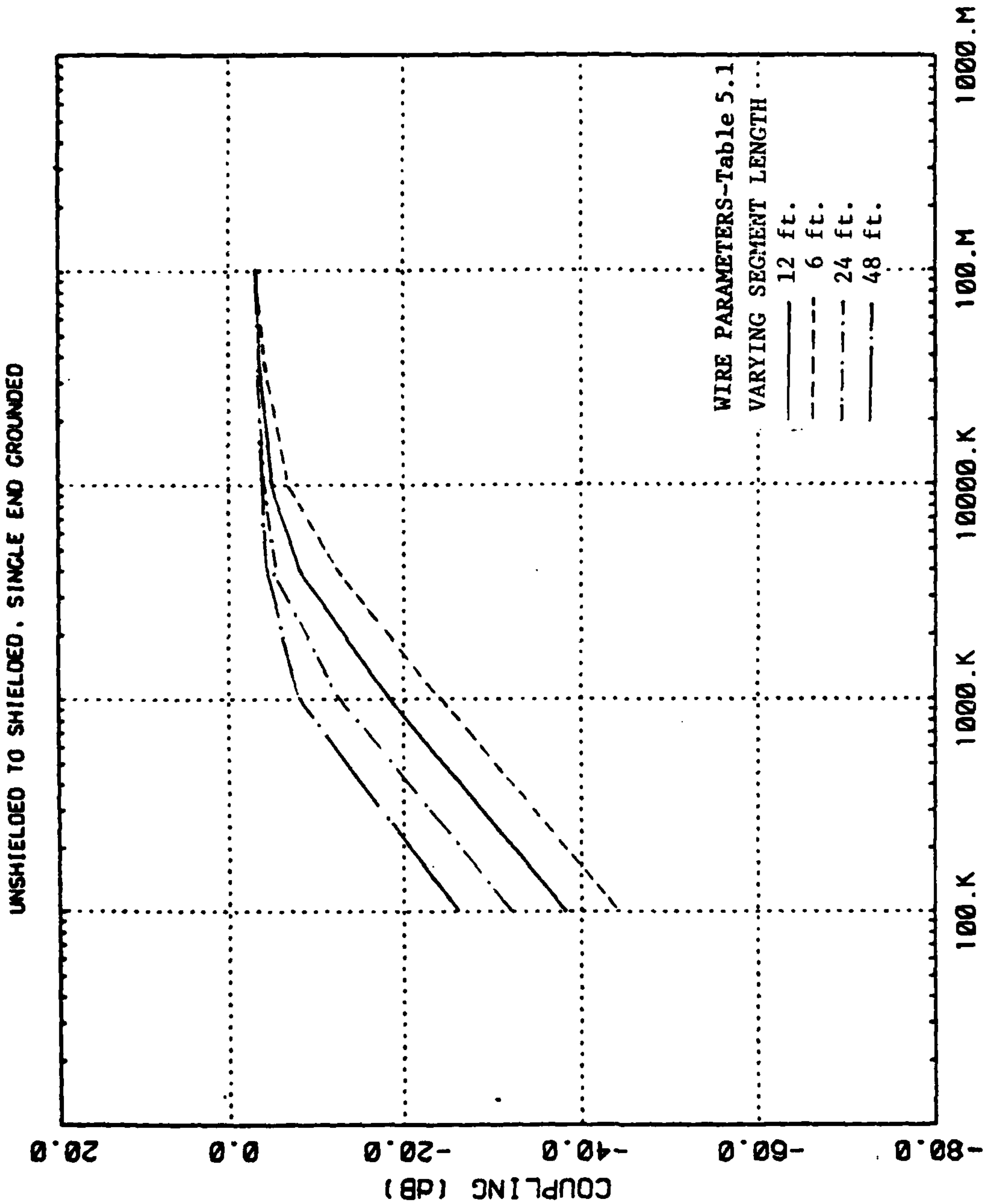

UNSHIELDED TO SHIELDED, SINGLE END GROUNDED
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 ft.
6 ft.
24 ft.
48 ft.
20.0
0.0
-20.0
-40.0
-60.0
-80.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.2.2c

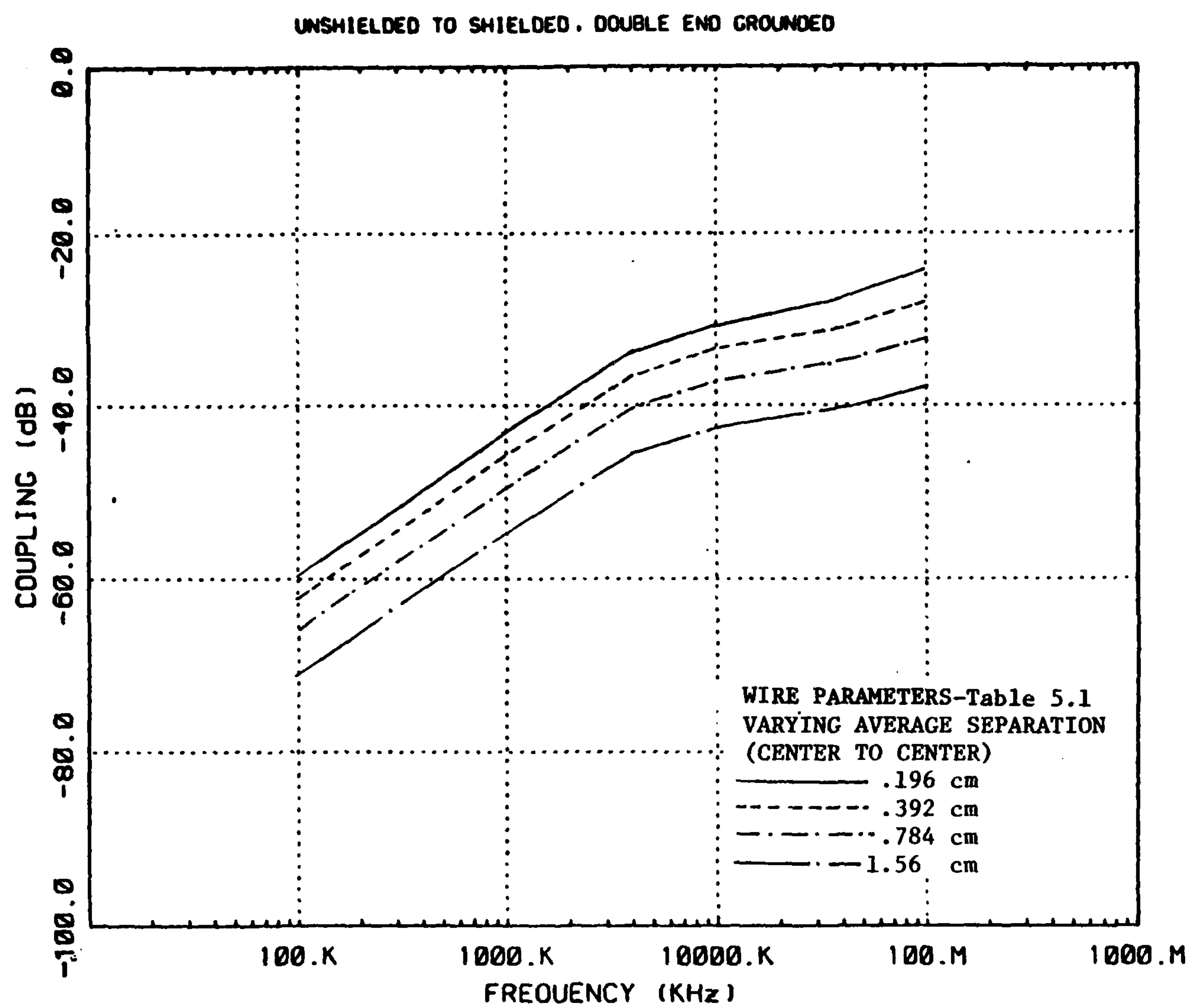

UNSHIELDED TO SHIELDED, DOUBLE END GROUNDED
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING AVERAGE SEPARATION
(CENTER TO CENTER)
.196 cm
.392 cm
.784 cm
1.56 cm

Figure 5.2.3a

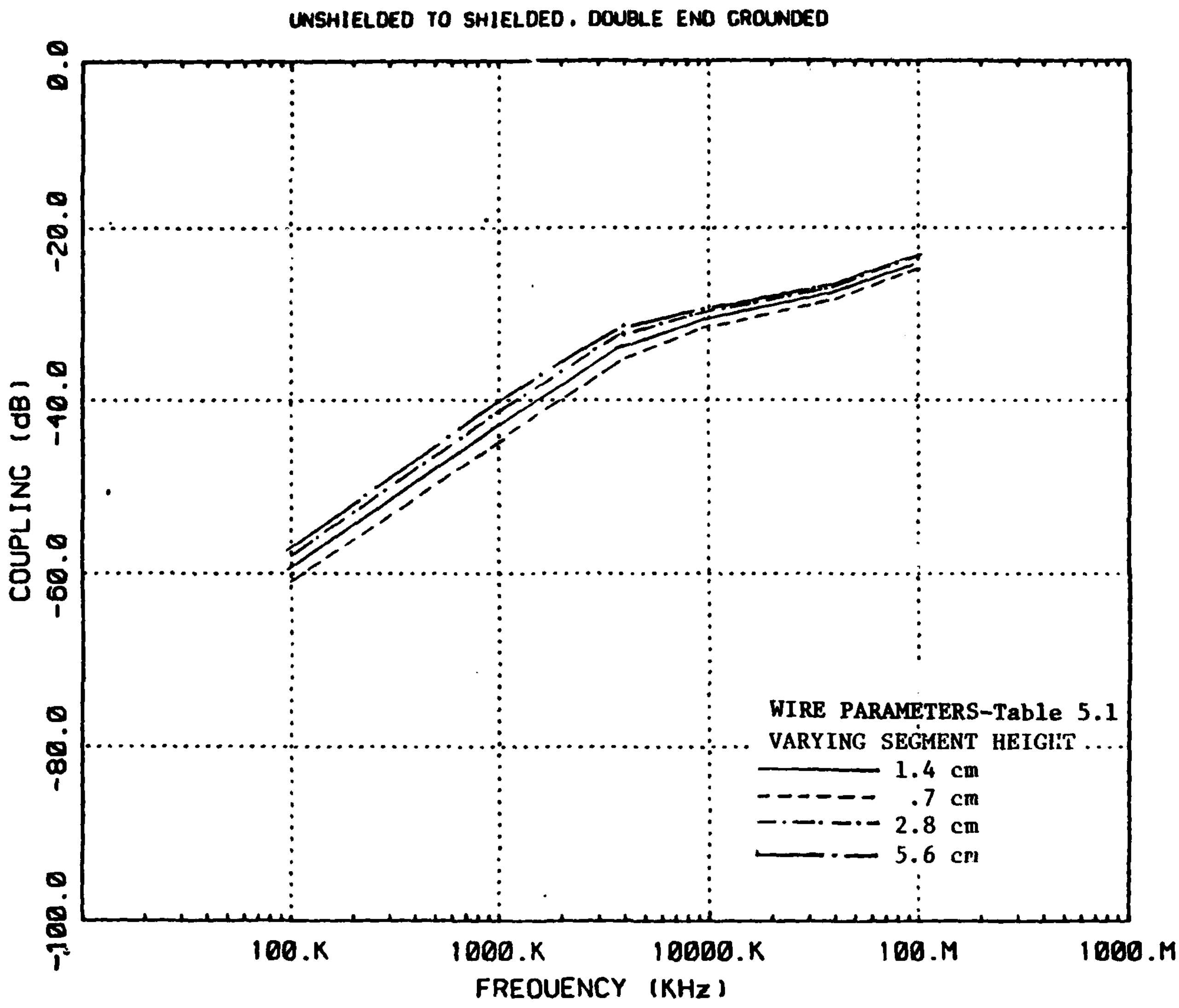
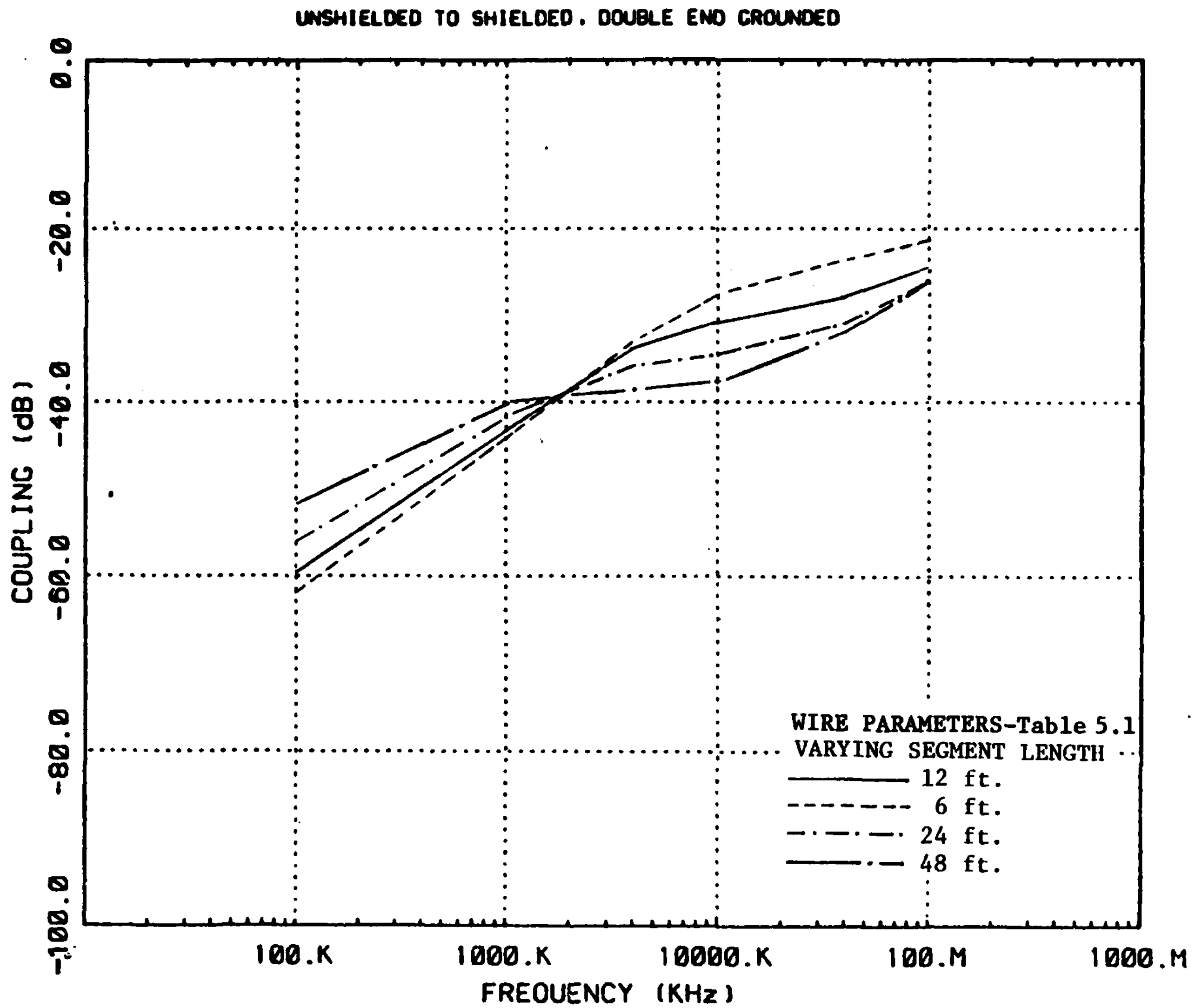

UNSHIELDED TO SHIELDED, DOUBLE END GROUNDED
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT HEIGHT
1.4 cm
.7 cm
2.8 cm
5.6 cm

Figure 5.2.3b



UNSHIELDED TO SHIELDED, DOUBLE END GROUNDED
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 ft.
6 ft.
24 ft.
48 ft.

Figure 5.2.3c

Table 5.4 Coupling Guidelines for an Unshielded Emitter Wire and a Single Shielded Receptor Wire

Wire Configuration	Variation Increment[a]	Coupling Correction (dB)[b]
Ungrounded		
• Average Wire Separation	$\pm$ 100%	$\pm$ 5.5 (100 kHz - 100 MHz)
• Segment Height	$\pm$ 100%	$\mp$ 3 (100 kHz - 16 MHz) < $\mp$ 1 (16 MHz - 100 MHz)
• Segment Length	$\pm$ 100%	$\mp$ 7 (100 kHz - 2 MHz) $\mp$ 2 (2 MHz - 100 MHz)
• Return Path	$\pm$ 100%	None
Single or Double End Grounded		
• Average Wire Separation • Segment Height • Segment Length	As above (no return path calculation done)	

a. A plus sign (+) indicates overestimate of parameter; a minus sign (-), underestimate.

b. The sign on the correction is correlated with the sign on the increment.

5.2.1.3 Single Shielded Emitter Wire to Unshielded Receptor

The third wire configuration to be analyzed was a single shielded emitter wire and an unshielded receptor wire. The baseline wire characteristics of each wire are given in Table 5.1. One shield grounding configuration was done:

- double end grounded

Five different sensitivity calculations were performed:

- variation of average wire separation
- variation of segment height
- variation of segment length for a fixed pigtail length
- variation of pigtail length for a fixed wire segment length
- variation of return wire path.

The calculated results are plotted in Figures 5.3a - 5.3e and the guidelines for this wire configuration are given in Table 5.5.

An analysis of the variation of the average wire separation, and segment height is similar to the discussion given in Section 5.1.1 for unshielded wires. The average wire separation was increased to cover larger separations than previously analyzed and the results are consistent with increasing the separation of other wire configurations discussed above. The guidelines are somewhat different, especially the guideline on average wire separation with a 10 dB variation in coupling for a 100% variation of wire separation.

A modification has been made to the variation of wire length calculation. The wire lengths were varied from 6 feet to 48 feet but with varying pigtail lengths as well. The first calculation (Figure 5.3c-1) considers variations in the wire lengths assuming no pigtails. The calculation is then repeated with pigtail lengths of 1/8 inch, 1/4 inch, 1/2 inch, 1 inch and 3 inches. All wires are electrically short together in the frequency range 100 kHz - 2 MHz. Beyond 2 MHz the curves either came very close or crossed each other. As the pigtail became longer, the crossing point shifted downward in frequency. The origin of this behavior is not completely known but part of the effect seems to be due to a breakdown in the wire coupling model for electrically long wires.

Pigtail lengths were varied on a wire bundle of fixed length (12 feet). The bundle is electrically short up to 16 MHz and in this range, Figure 5.3d indicates a 2dB variation on the average.

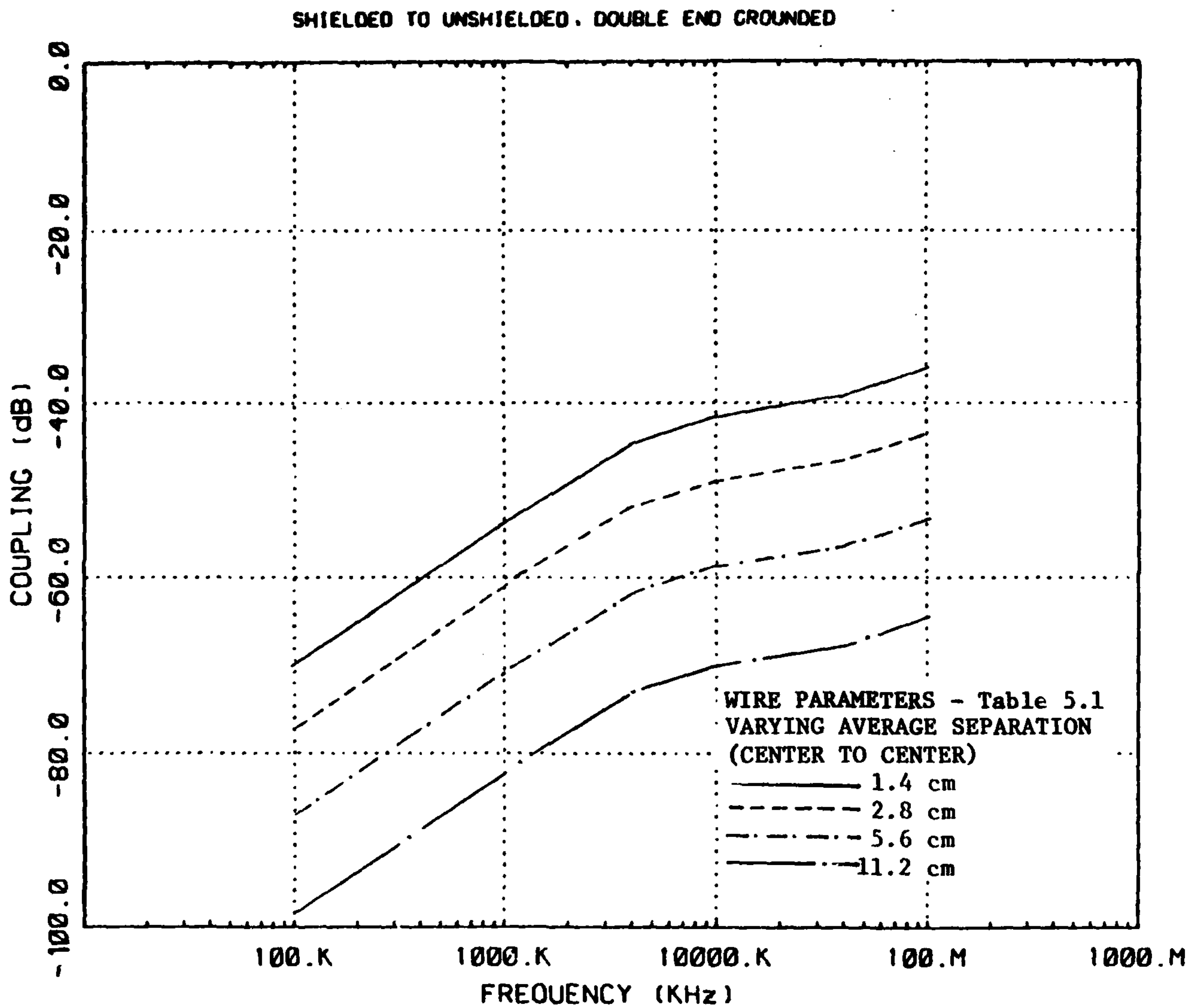

SHIELDED TO UNSHIELDED. DOUBLE END GROUNDED
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING AVERAGE SEPARATION
(CENTER TO CENTER)
1.4 cm
2.8 cm
5.6 cm
11.2 cm

Figure 5.3a

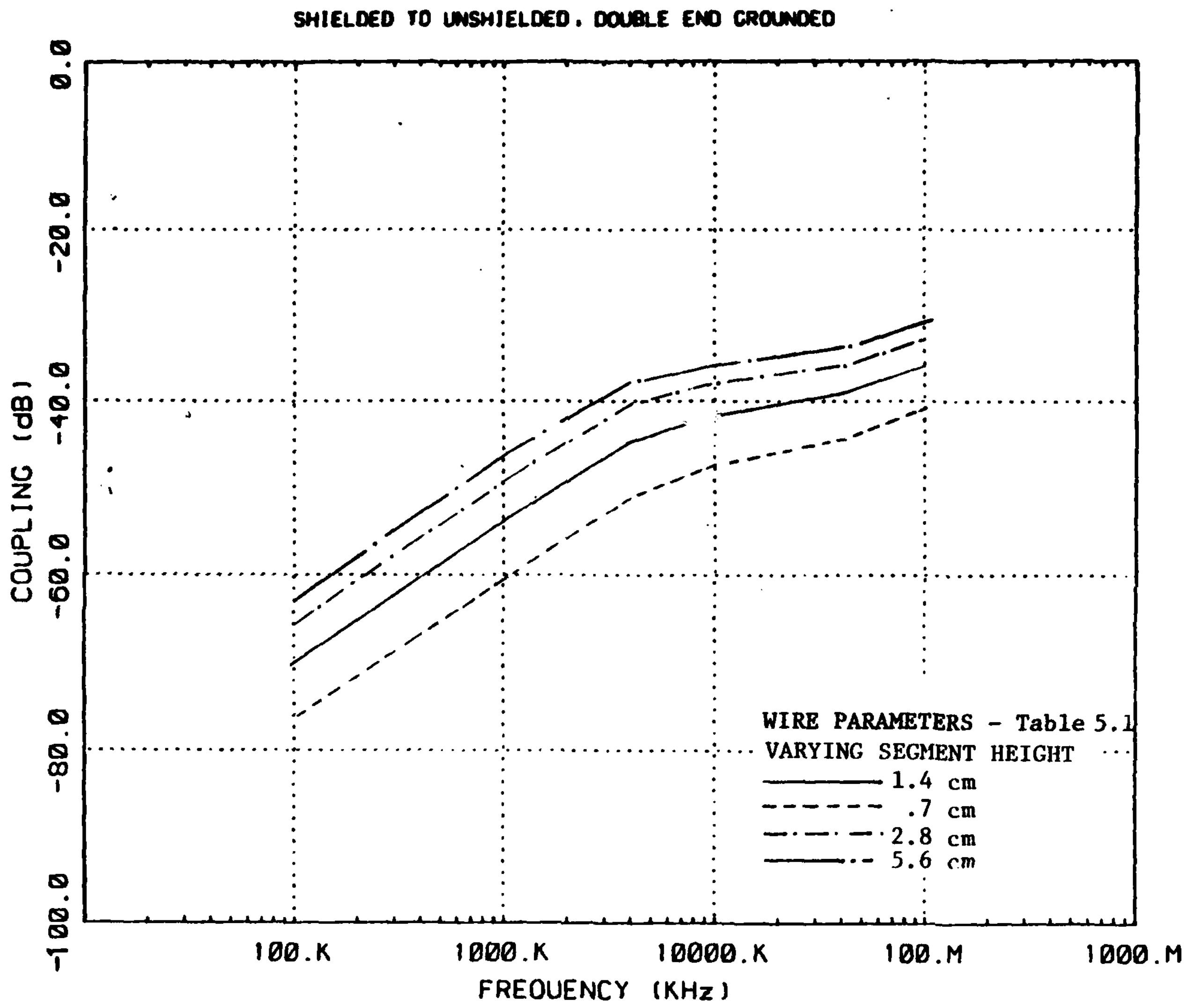
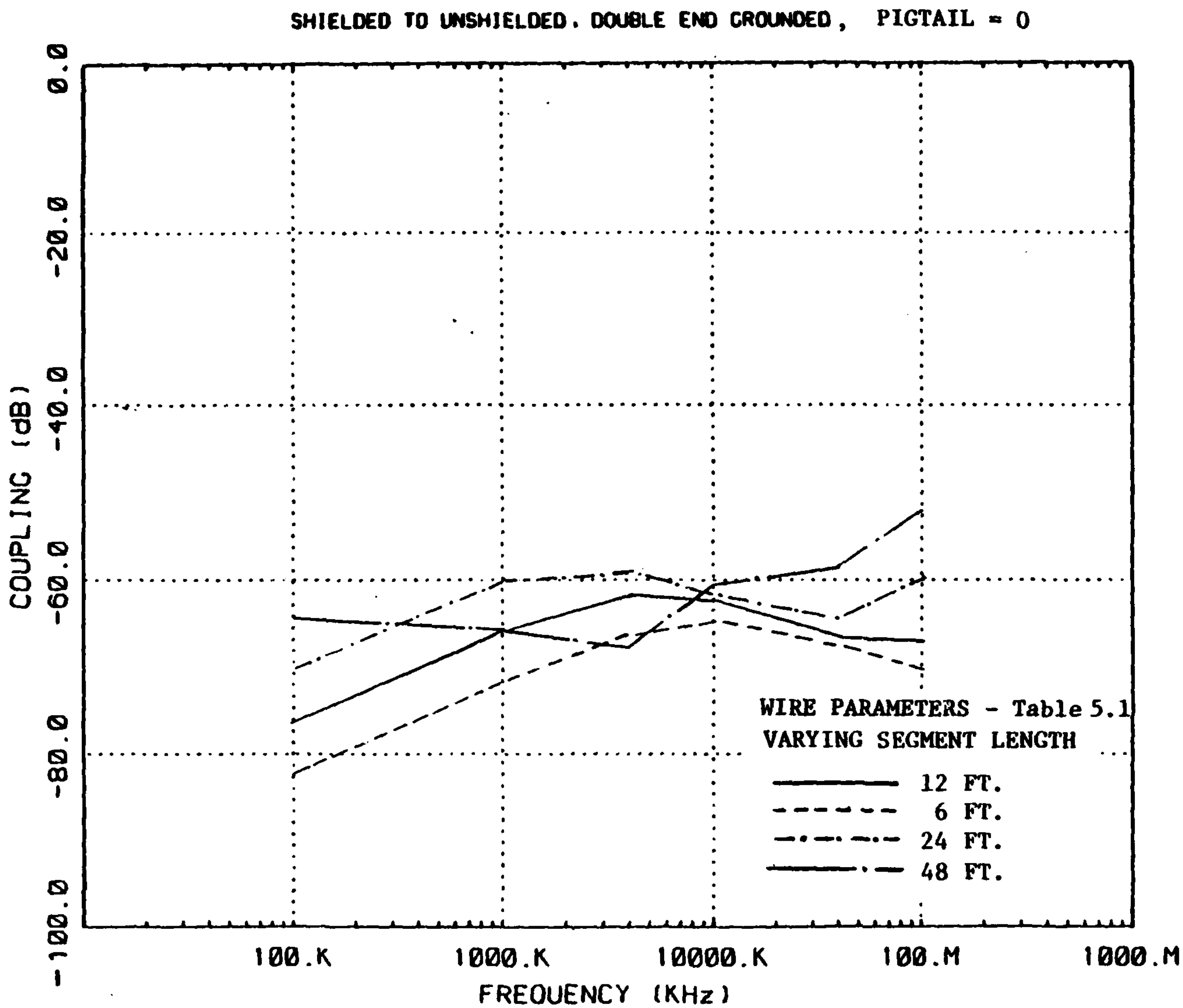

SHIELDED TO UNSHIELDED, DOUBLE END GROUNDED
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT HEIGHT
1.4 cm
.7 cm
2.8 cm
5.6 cm
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.3b



SHIELDED TO UNSHIELDED. DOUBLE END GROUNDED, PIGTAIL = 0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.3c-1

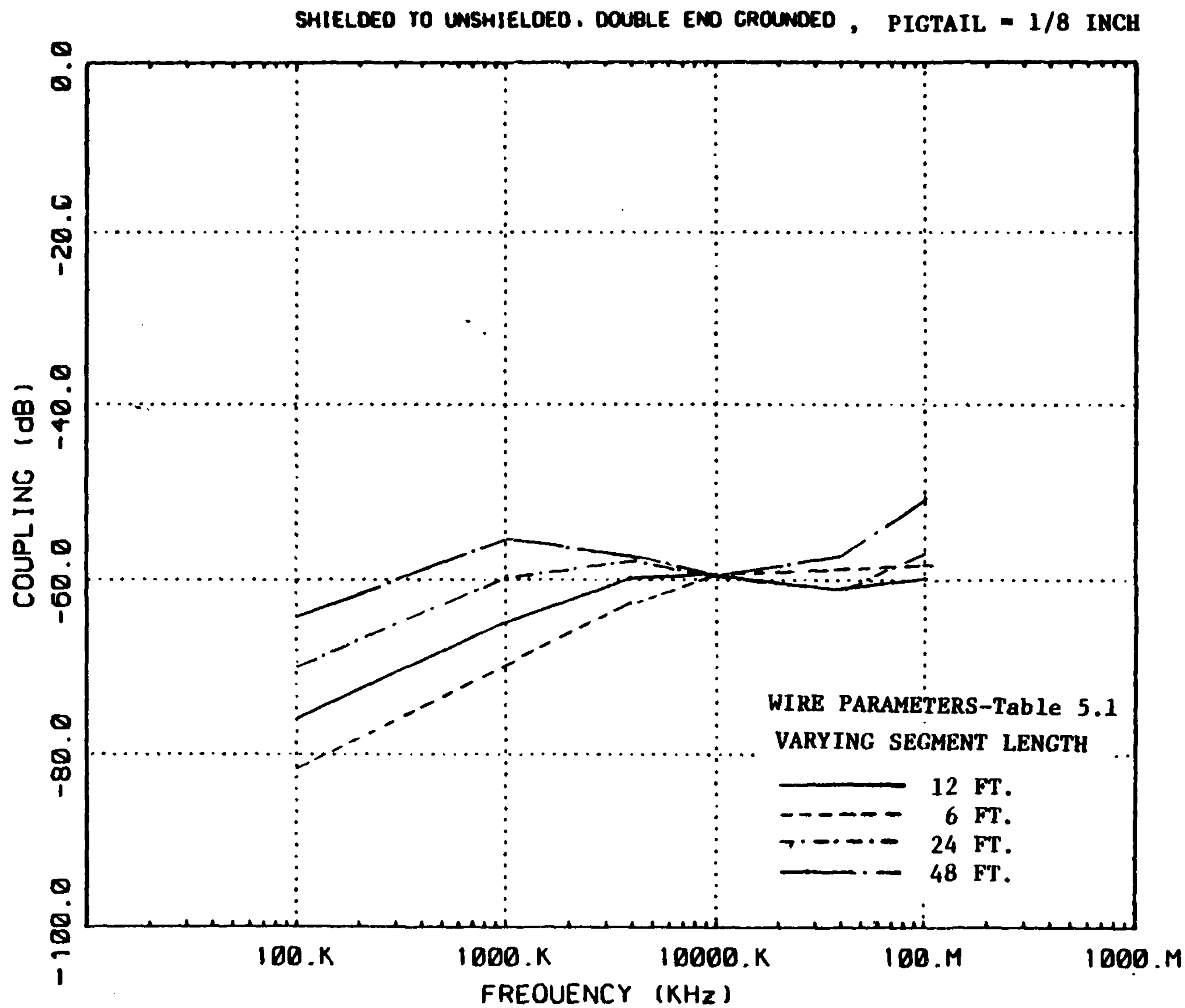
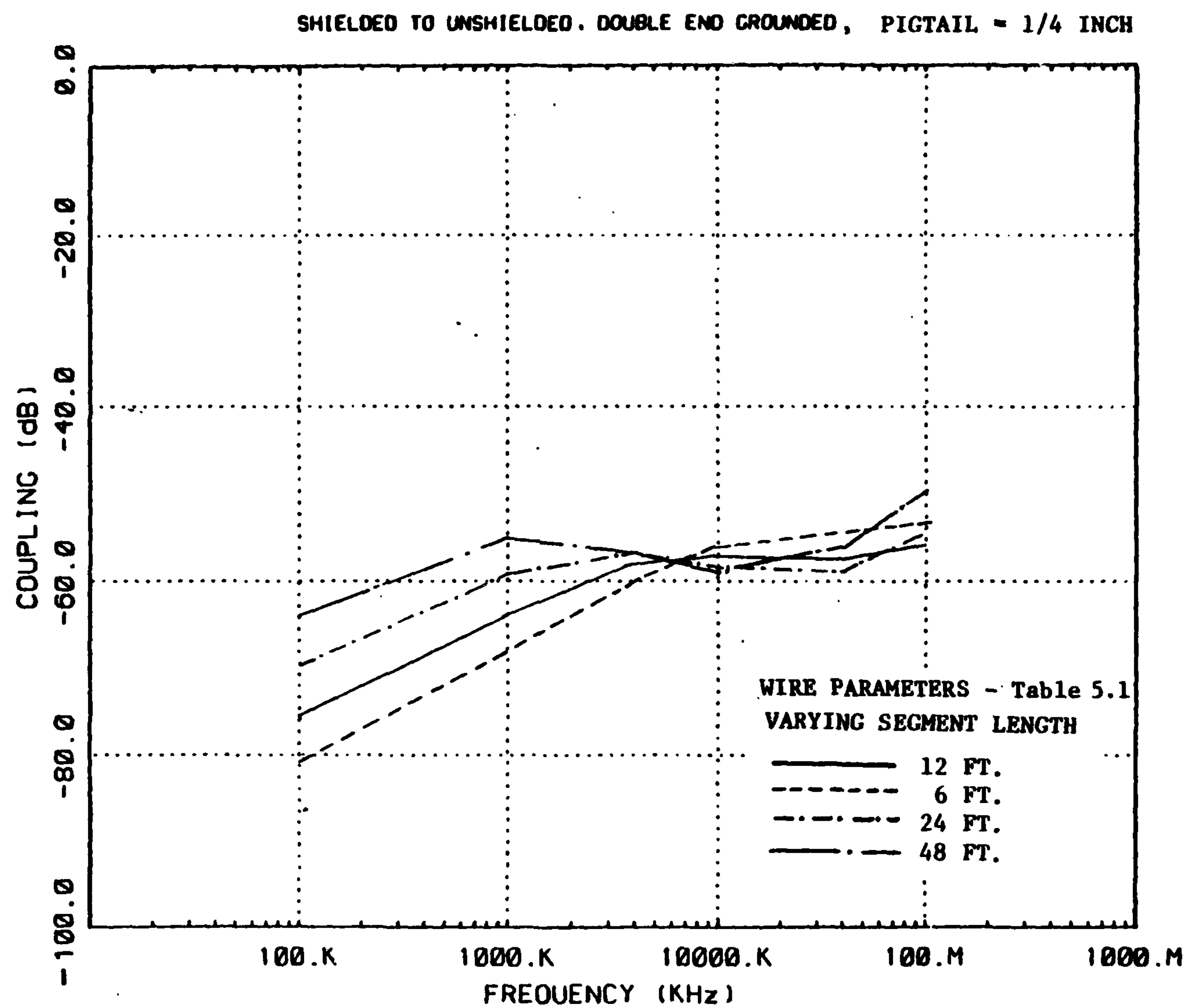

SHIELDED TO UNSHIELDED, DOUBLE END GROUNDED , PIGTAIL = 1/8 INCH
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.3c-2



SHIELDED TO UNSHIELDED. DOUBLE END GROUNDED, PIGTAIL = 1/4 INCH
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.3c-3

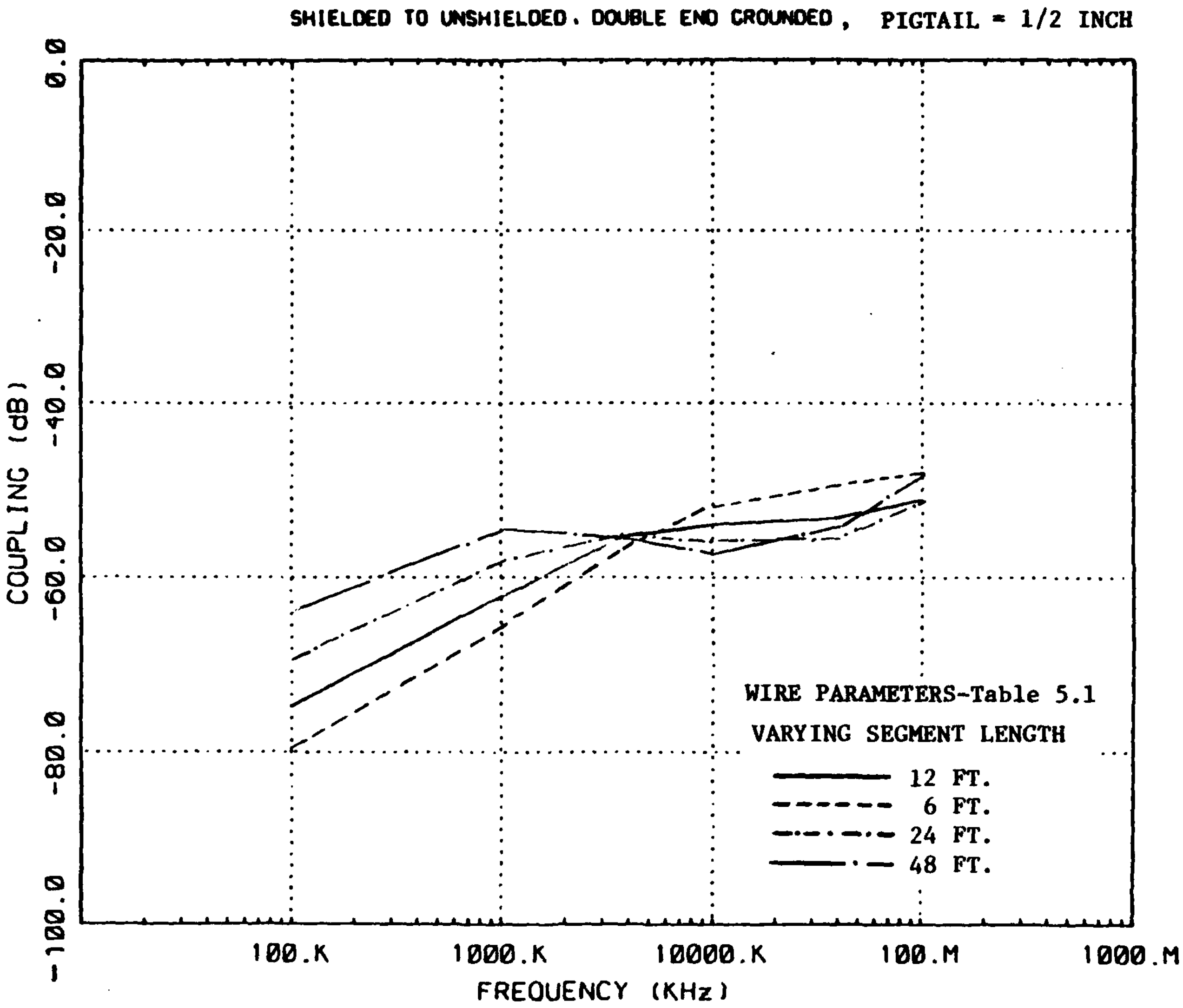

SHIELDED TO UNSHIELDED. DOUBLE END GROUNDED , PIGTAIL = 1/2 INCH
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.3c-4

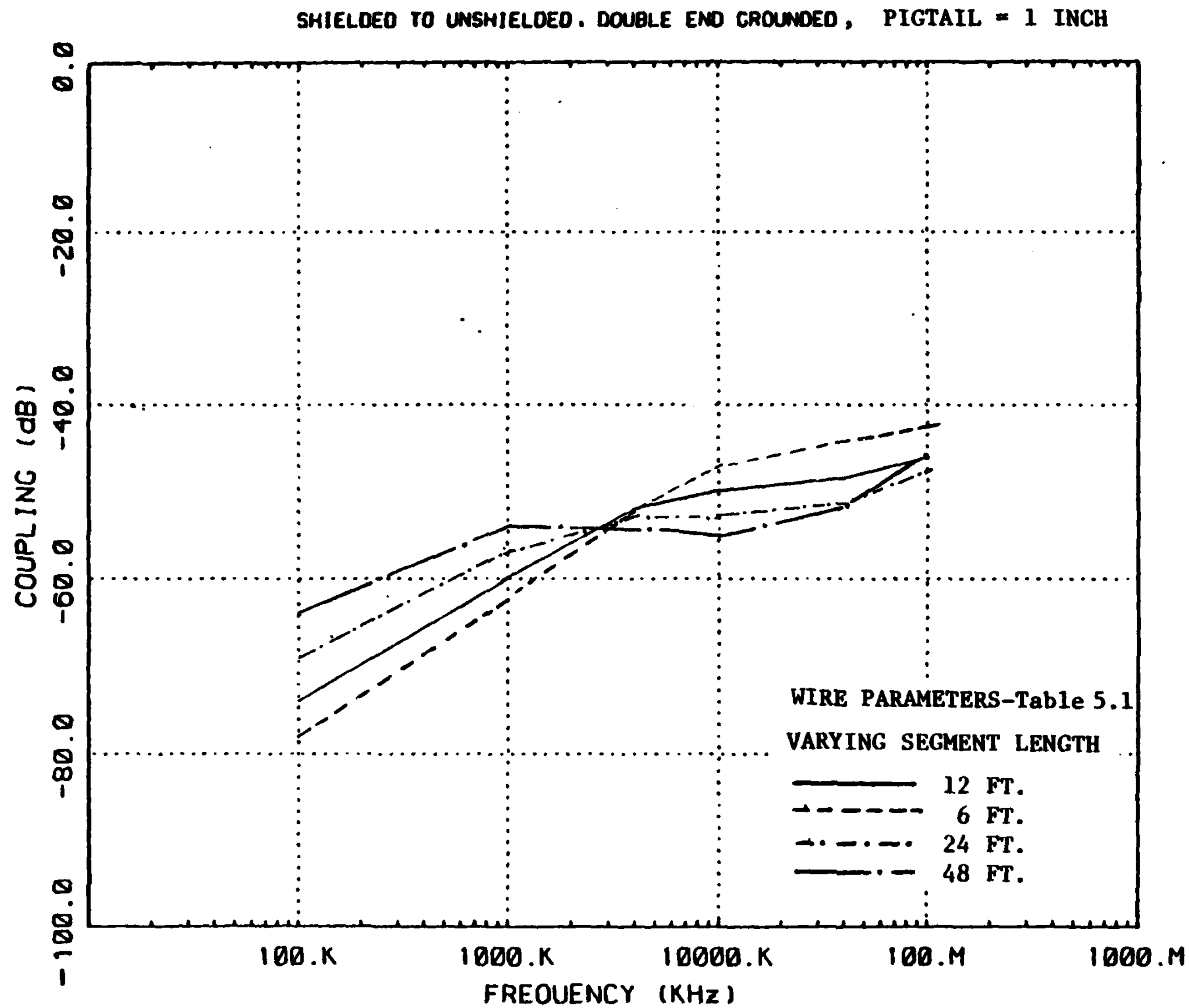
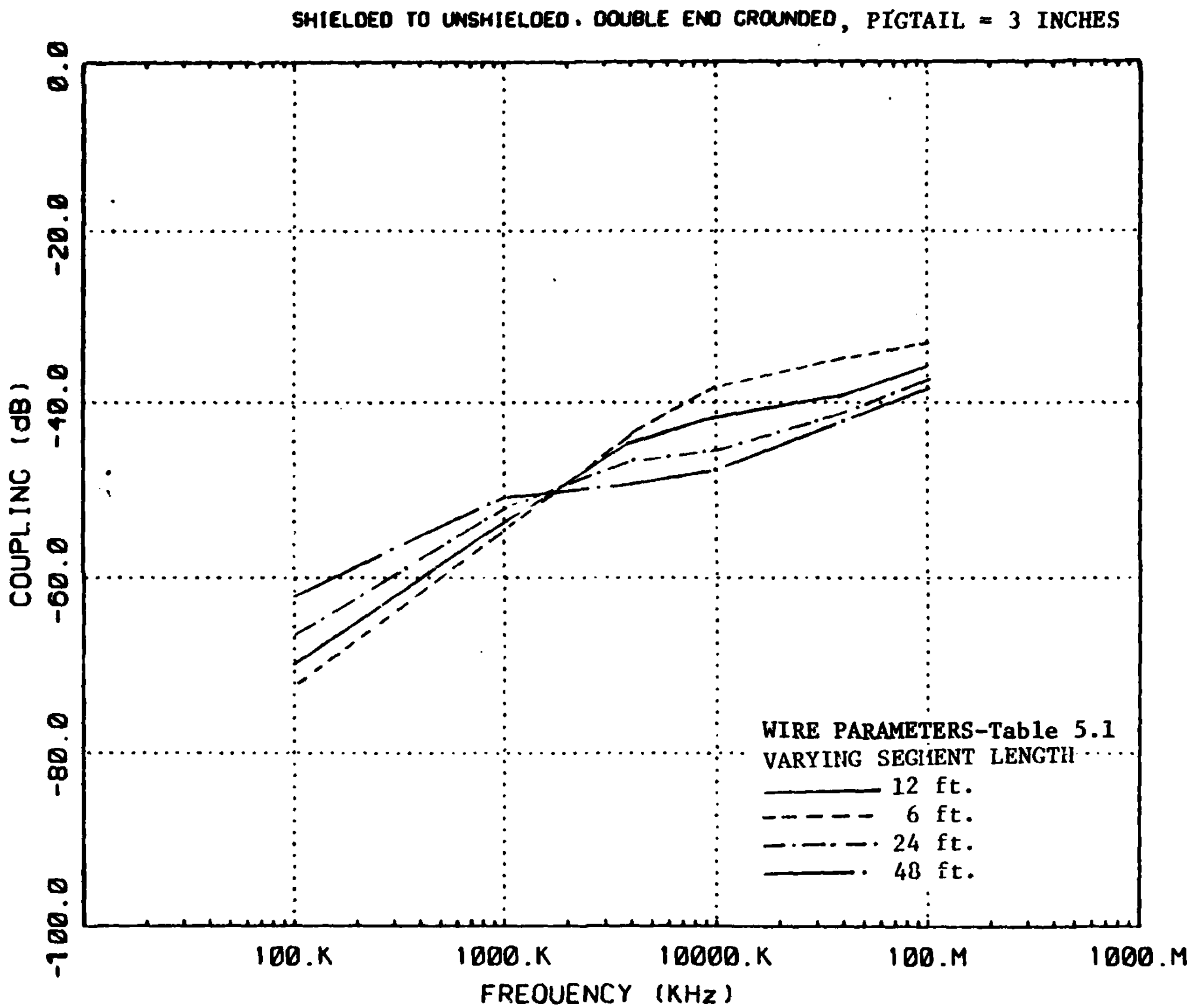

SHIELDED TO UNSHIELDED. DOUBLE END GROUNDED, PIGTAIL = 1 INCH
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.3c-5



SHIELDED TO UNSHIELDED, DOUBLE END GROUNDED, PIGTAIL = 3 INCHES
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 ft.
6 ft.
24 ft.
48 ft.

Figure 5.3c-6

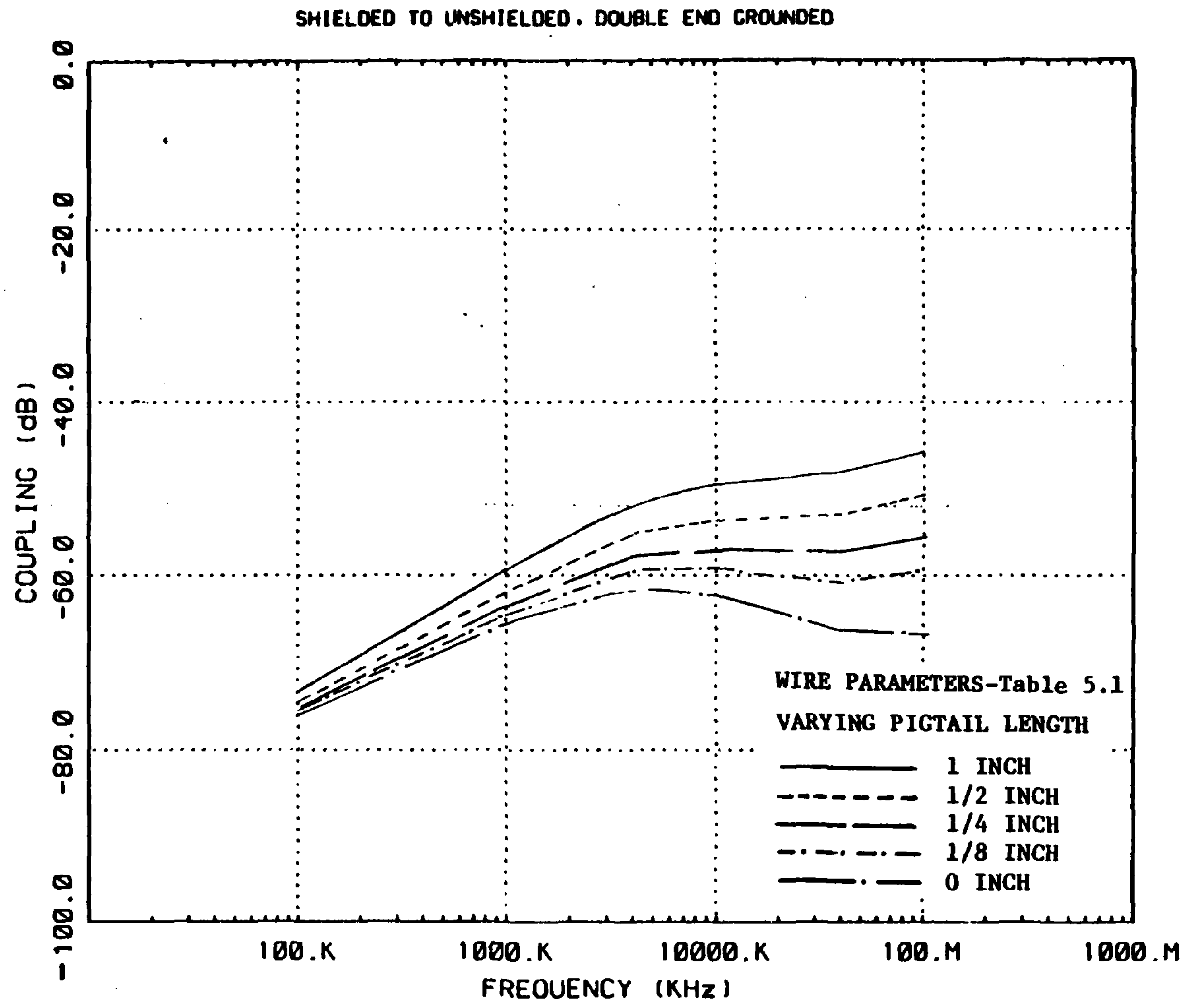

SHIELDED TO UNSHIELDED, DOUBLE END GROUNDED
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING PIGTAIL LENGTH
1 INCH
1/2 INCH
1/4 INCH
1/8 INCH
0 INCH

Figure 5.3d

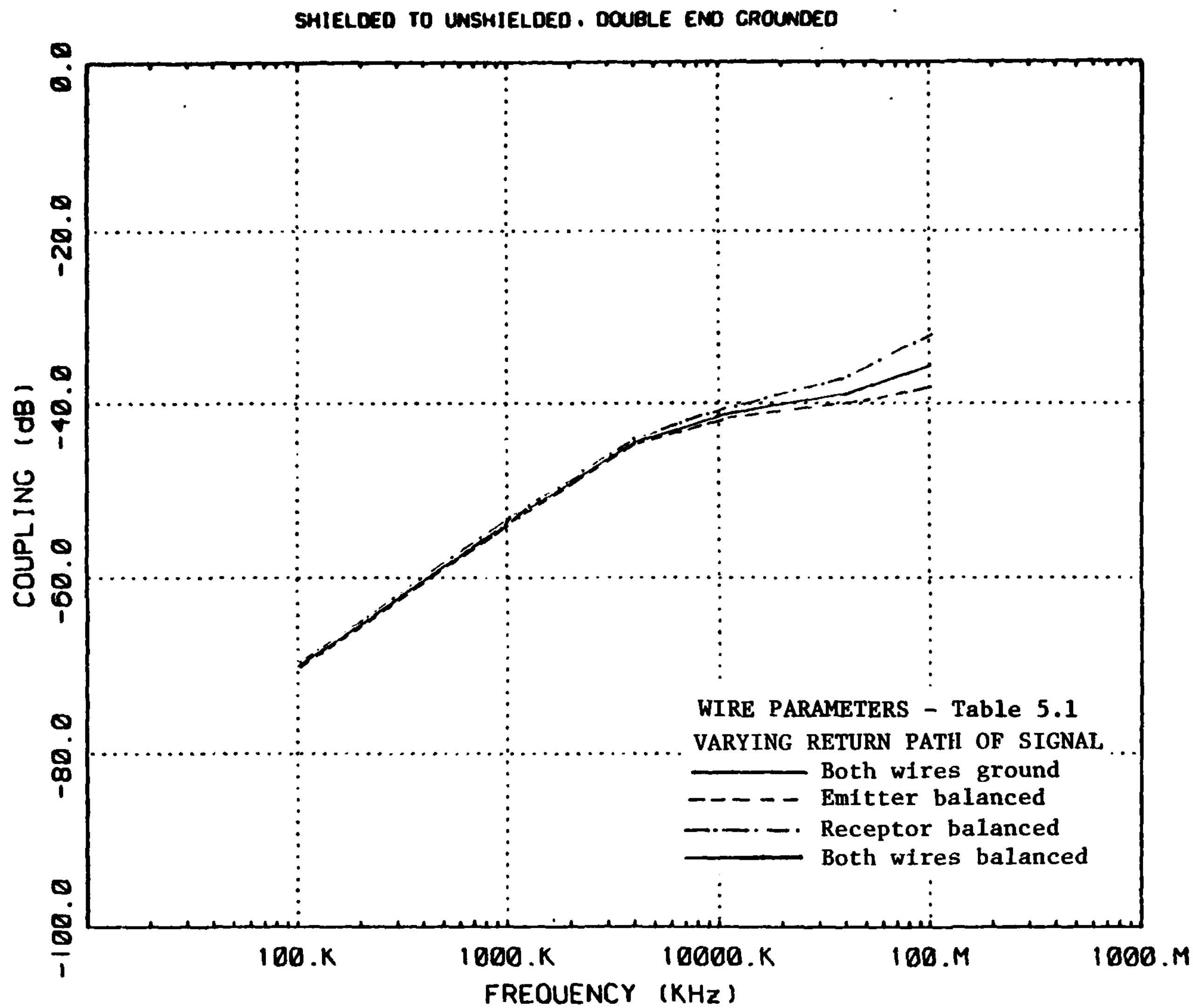

SHIELDED TO UNSHIELDED, DOUBLE END GROUNDED
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING RETURN PATH OF SIGNAL
Both wires ground
Emitter balanced
Receptor balanced
Both wires balanced

Figure 5.3e

Table 5.5 Coupling Guidelines for Single Shielded Emitter Wire And An Unshielded Reception Wire - Double End Grounded

Parameter Varied	Variation Increment[a]	Coupling Correction (dB)[b]
Average Wire Separation	± 100%	± 10 (100 kHz - 100 MHz)
Segment Height	± 100%	± 5 (100 kHz - 16 MHz) ± 3 (16 MHz - 100 MHz)
Segment Length and Pigtail Length	± 100%	± 7 (100 kHz - 2 MHz) unreliable(2 MHz - 100 MHz)
Pigtail Length	± 100%	± 2 (100 kHz - 16 MHz)
Return Path	± 100%	No Change

a. A pulse sign (+) indicates overestimate of parameter; a minus sign (-), underestimate.

b. The sign on the coupling correction is correlated with the sign on the increment.

Varying the return path had practically no effect on the coupling curves (Figure 5.3e)

5.2.1.4 Both Wires Single Shielded

The fourth wire configuration to be analyzed was the case of both wires single shielded. The baseline wire characteristics are located in Table 5.1. Only one shield grounding configuration was considered:

- double end grounded

Five different sensitivity calculations were performed;

- variation of average wire separation
- variation of segment height
- variation of segment length for a fixed pigtail length
- variation of pigtail length for a fixed wire segment length
- variation of return wire path.

The results of the sensitivity calculations are shown in Figures 5.4a - 5.4e. The guidelines are given in Table 5.6.

Variations in segment height and average wire separation are similar to previously treated wire configurations and the earlier discussions apply to the cases considered here.

As in the previous section, the wire segment length is varied for several fixed lengths of pigtail. The same general behavior is observed when both wires are single shielded as when one wire is single shielded. Again the coupling curves cross but this time the frequency at which they cross is lower and crossing takes place even when the wires are electrically small. It is not clear at this point whether this behavior is valid, or due to a breakdown in the models. More investigation of this phenomena is desirable.

Variations in pigtail length for a fixed length wire segment gives very smooth behavior similar to the single shielded wire results of the previous section.

5.2.1.5 Emitter Wire Unshielded and Receptor Wire Double Shielded

The fifth wire configuration to be analyzed was the case of the emitter wire unshielded and the receptor wire double shielded. The baseline wire characteristics are located in Table 5.1. Only one shield grounding configuration was considered:

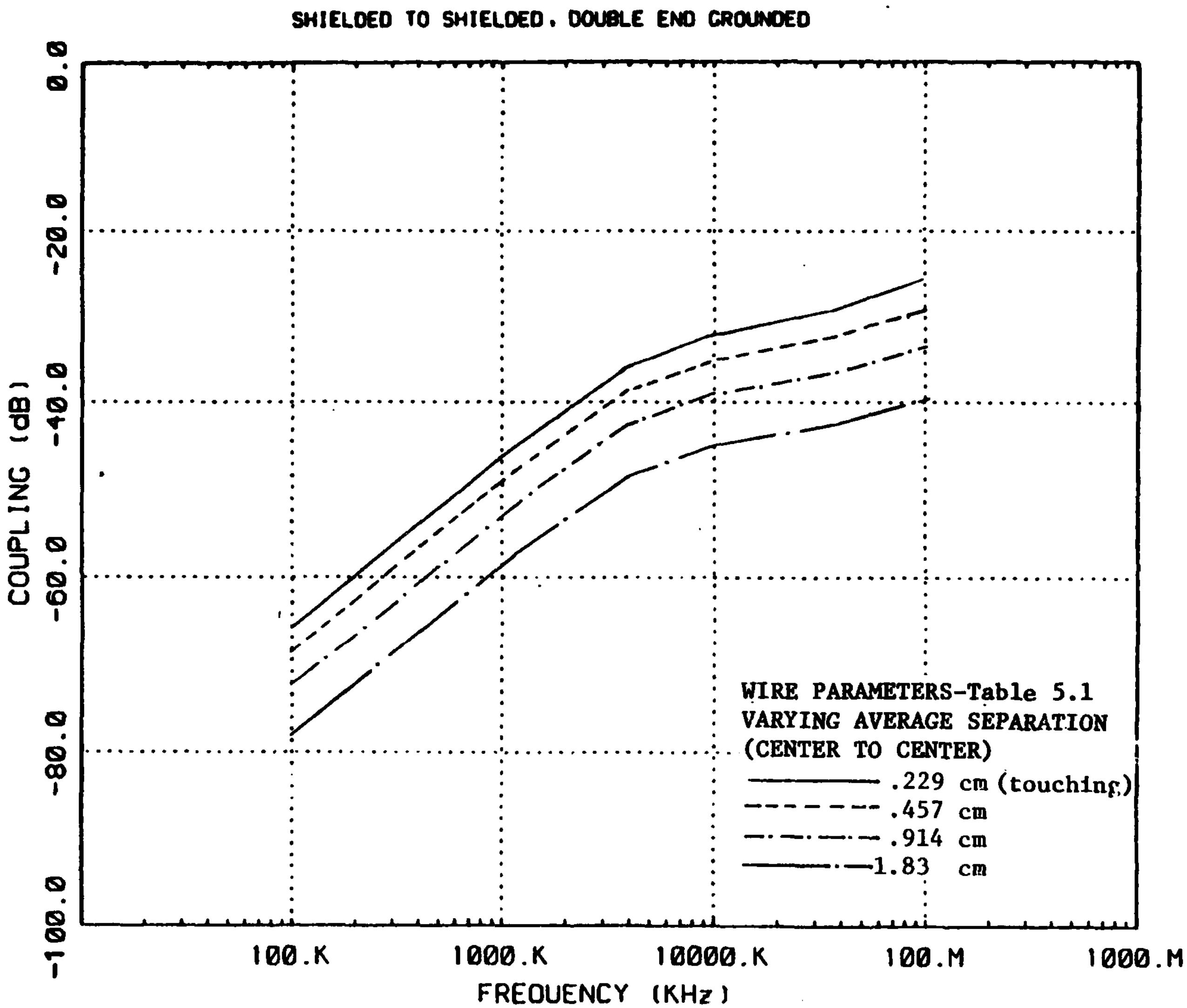

SHIELDED TO SHIELDED, DOUBLE END GROUNDED
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING AVERAGE SEPARATION
(CENTER TO CENTER)
.229 cm (touching)
.457 cm
.914 cm
1.83 cm

Figure 5.4a

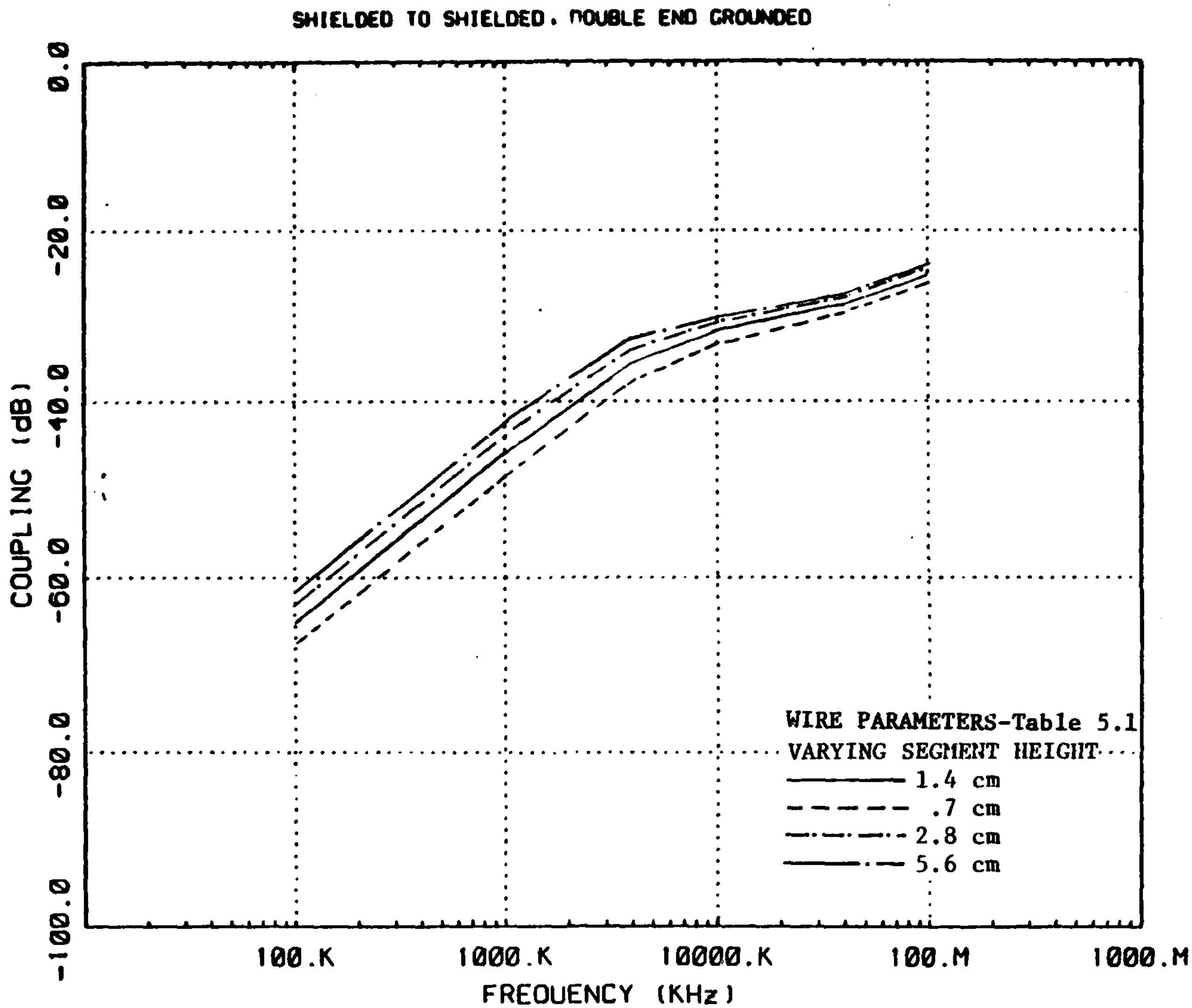

SHIELDED TO SHIELDED. DOUBLE END GROUNDED
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT HEIGHT
1.4 cm
.7 cm
2.8 cm
5.6 cm

Figure 5.4b

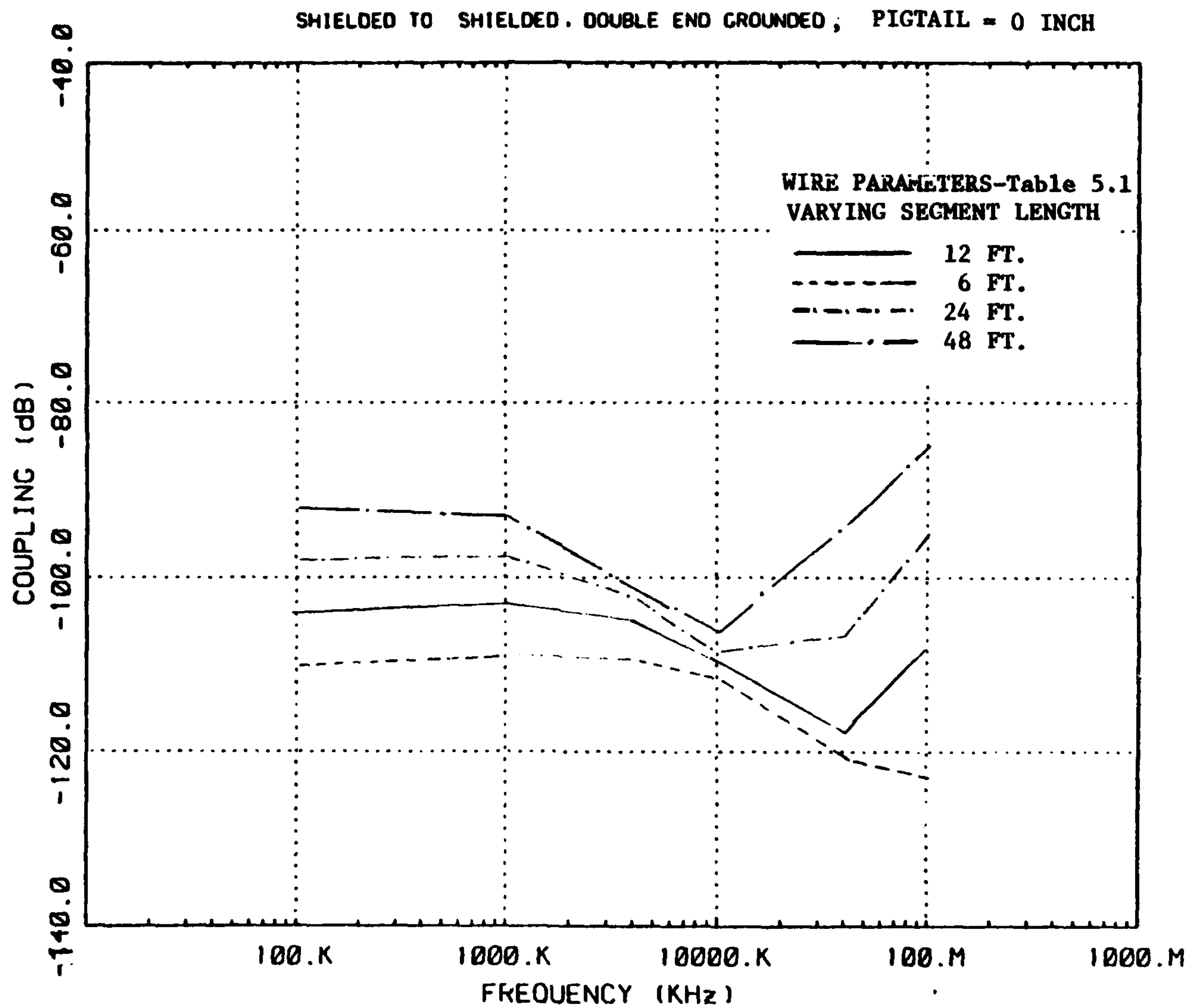
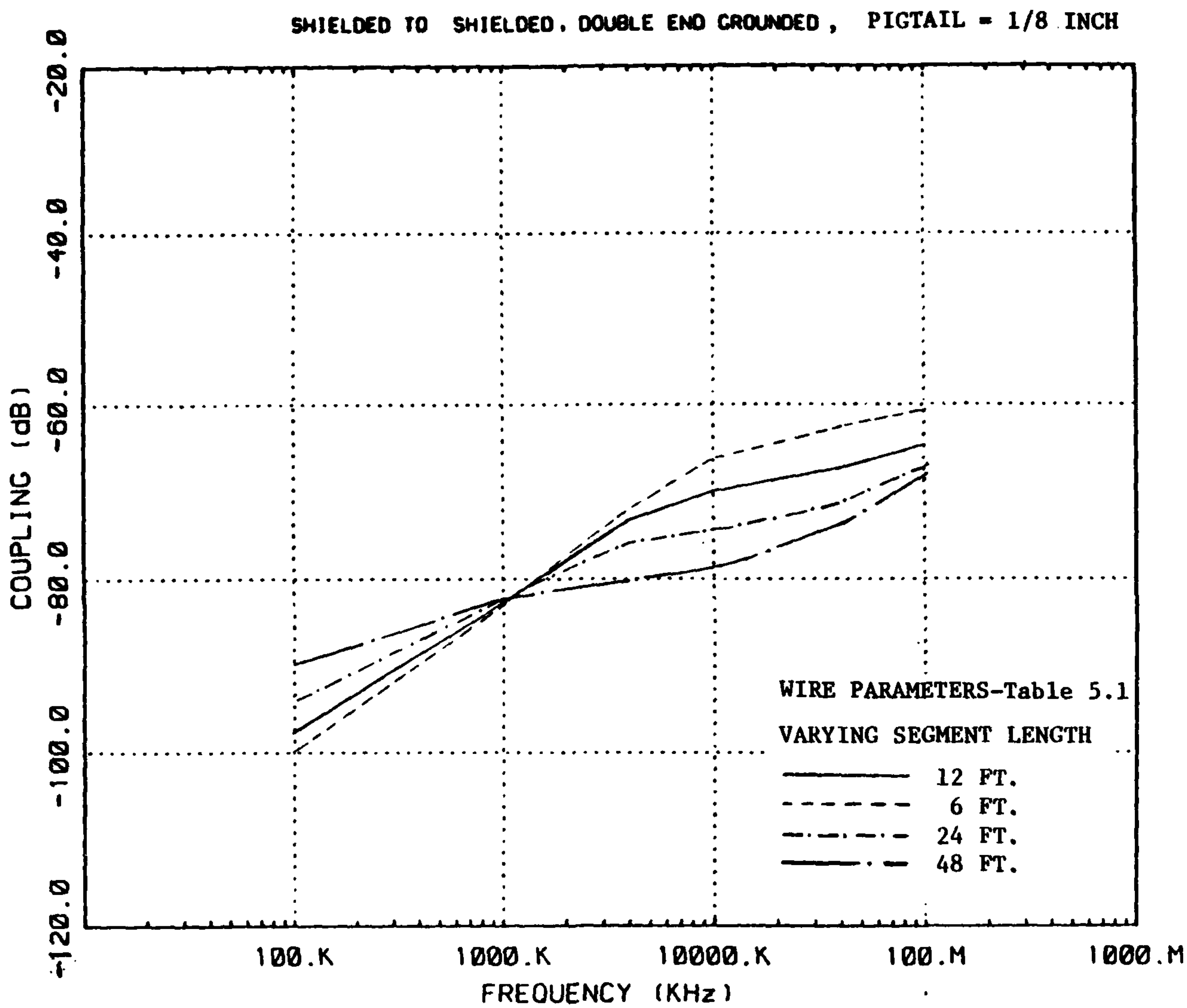
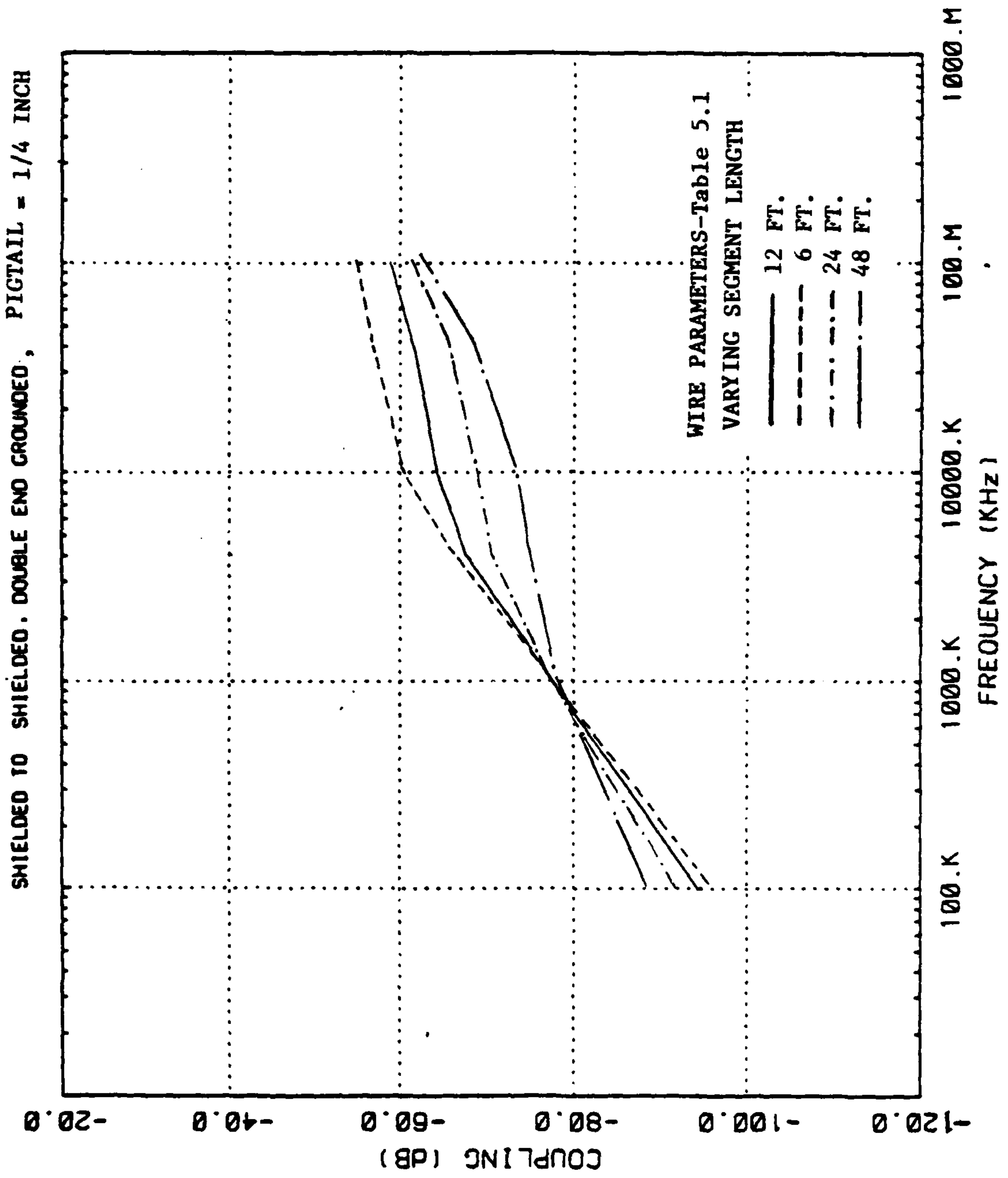

SHIELDED TO SHIELDED. DOUBLE END GROUNDED; PIGTAIL = 0 INCH
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.4c-1



SHIELDED TO SHIELDED, DOUBLE END GROUNDED, PIGTAIL = 1/8 INCH
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.4c-2



SHIELDED TO SHIELDED, DOUBLE END GROUNDED, PIGTAIL = 1/4 INCH
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.4c-3

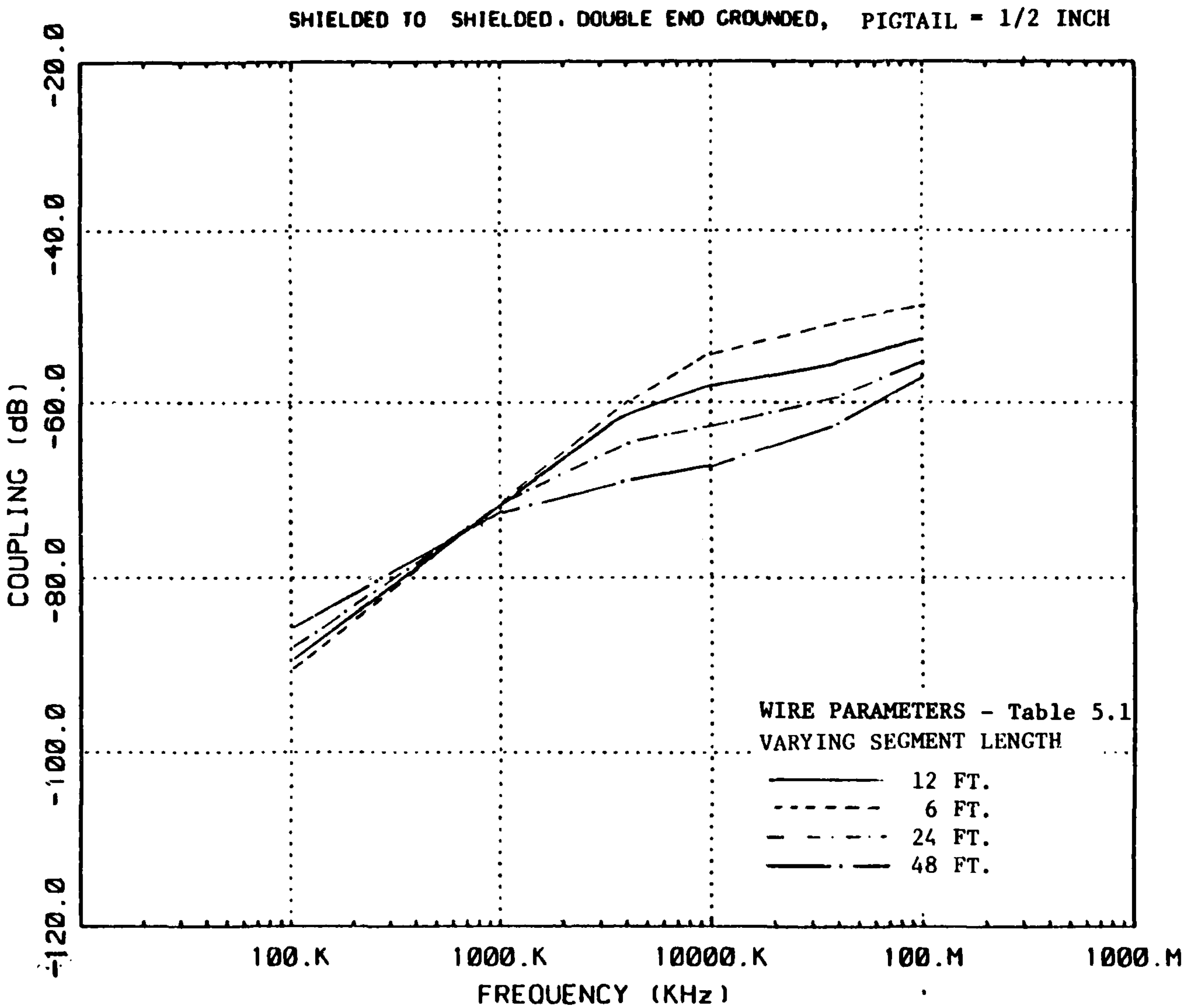
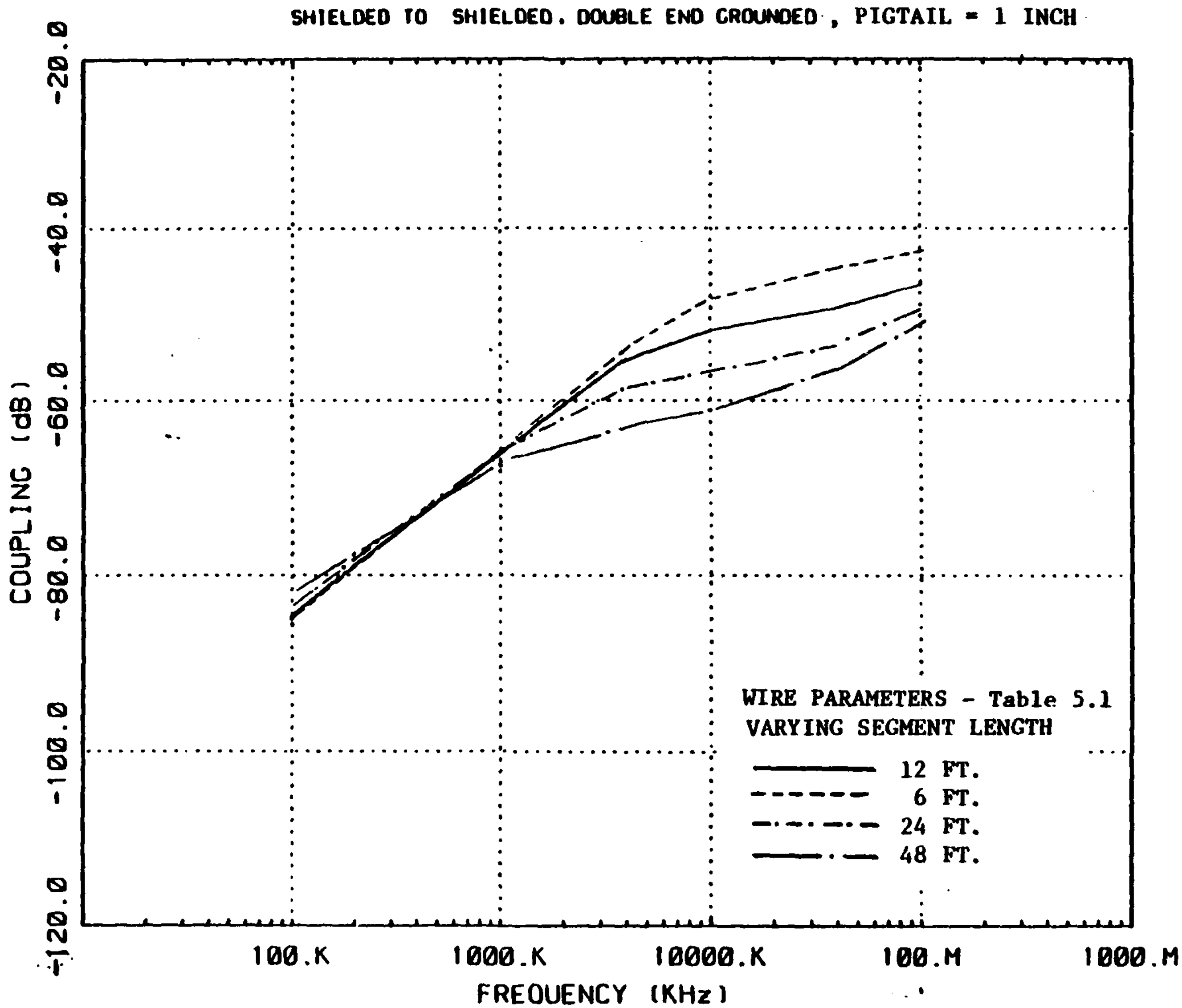
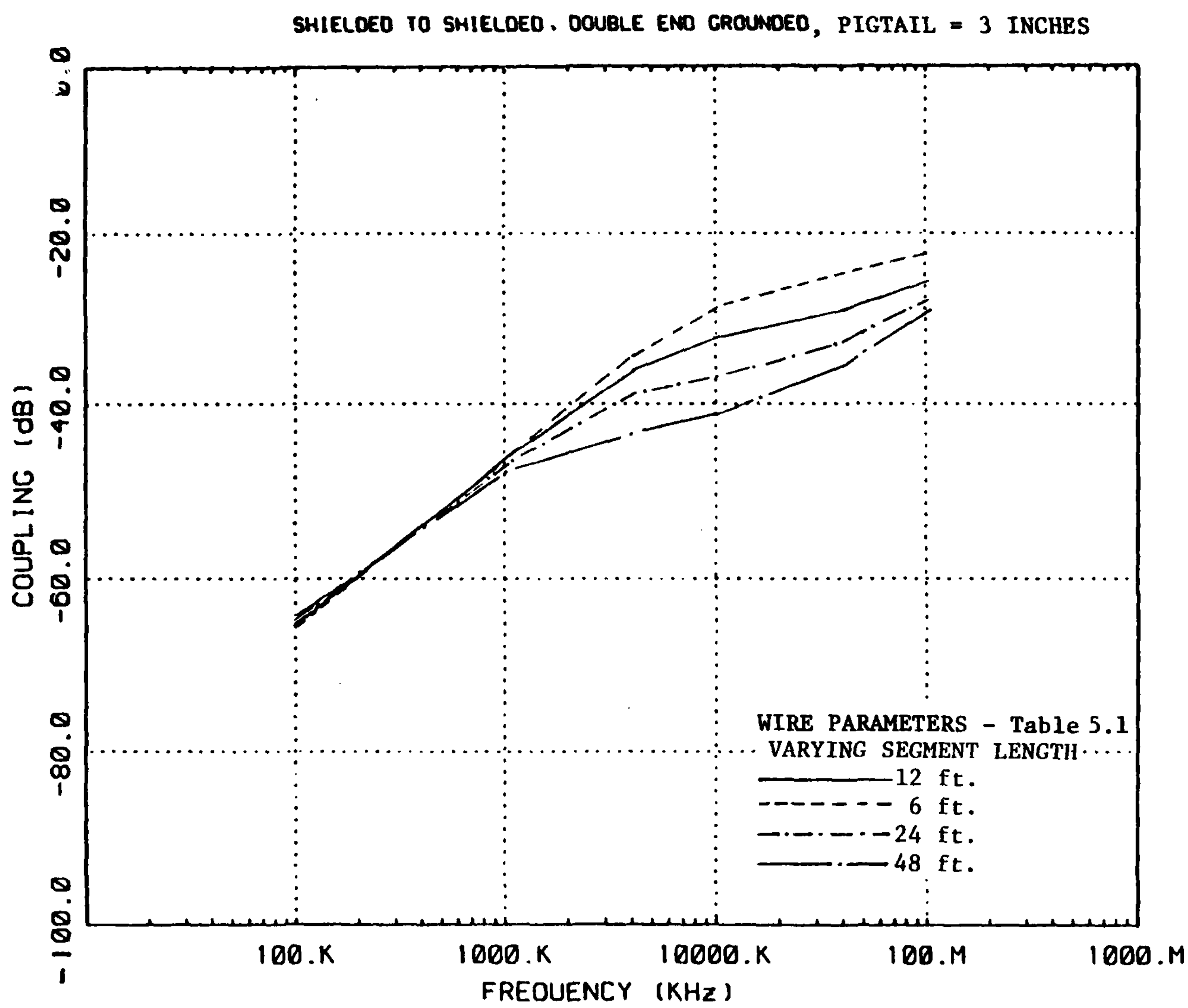

SHIELDED TO SHIELDED. DOUBLE END GROUNDED, PIGTAIL = 1/2 INCH
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.4c-4



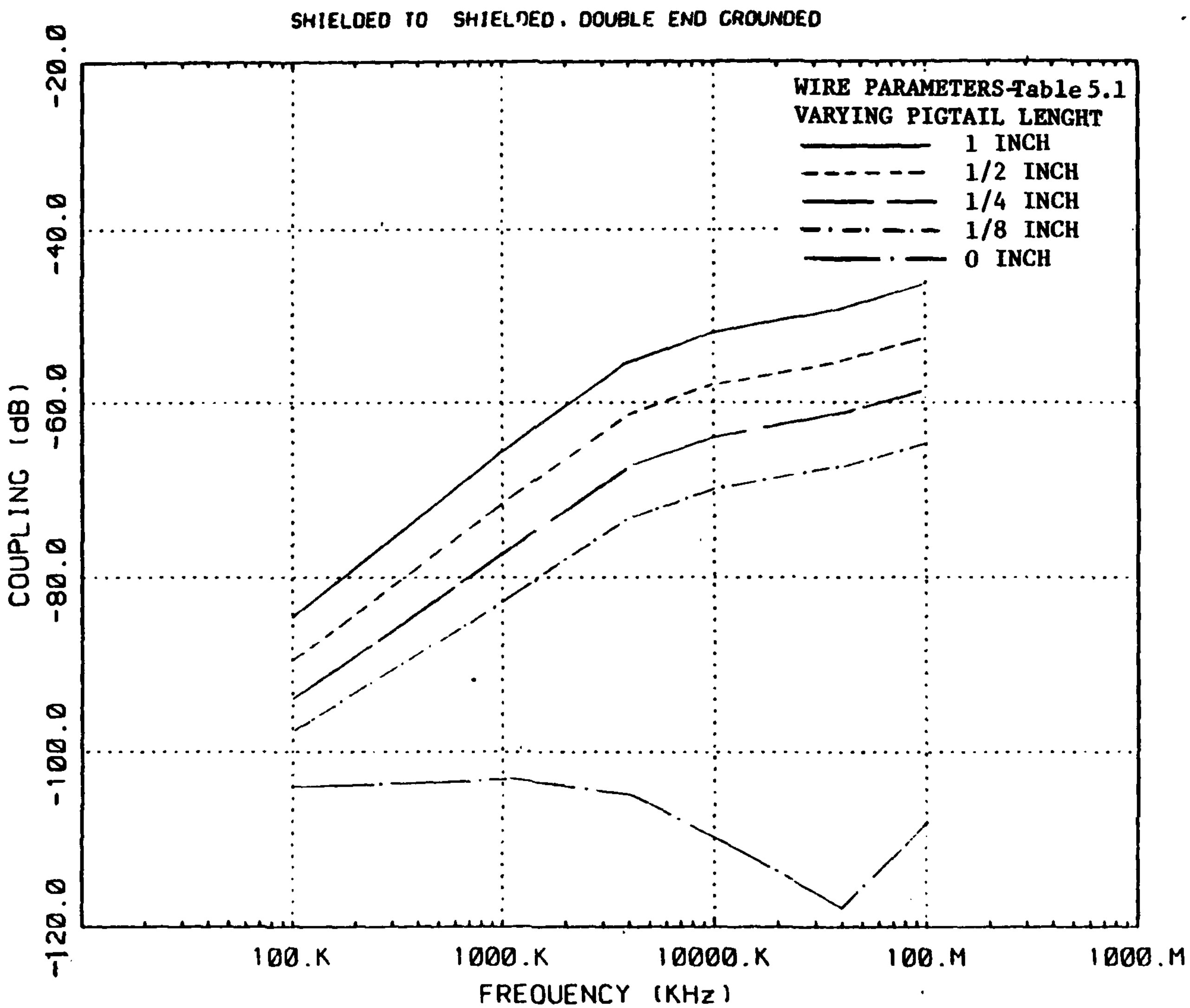
SHIELDED TO SHIELDED. DOUBLE END GROUNDED , PIGTAIL = 1 INCH
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT LENGTH
12 FT.
6 FT.
24 FT.
48 FT.

Figure 5.4c-5



SHIELDED TO SHIELDED, DOUBLE END GROUNDED, PIGTAIL = 3 INCHES
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS - Table 5.1
VARYING SEGMENT LENGTH
12 ft.
6 ft.
24 ft.
48 ft.

Figure 5.4c-6



SHIELDED TO SHIELDED, DOUBLE END GROUNDED
WIRE PARAMETERS-Table 5.1
VARYING PIGTAIL LENGHT
1 INCH
1/2 INCH
1/4 INCH
1/8 INCH
0 INCH
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
COUPLING (dB)
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)

Figure 5.4d

SHIELDED TO SHIELDED, DOUBLE END GROUNDED

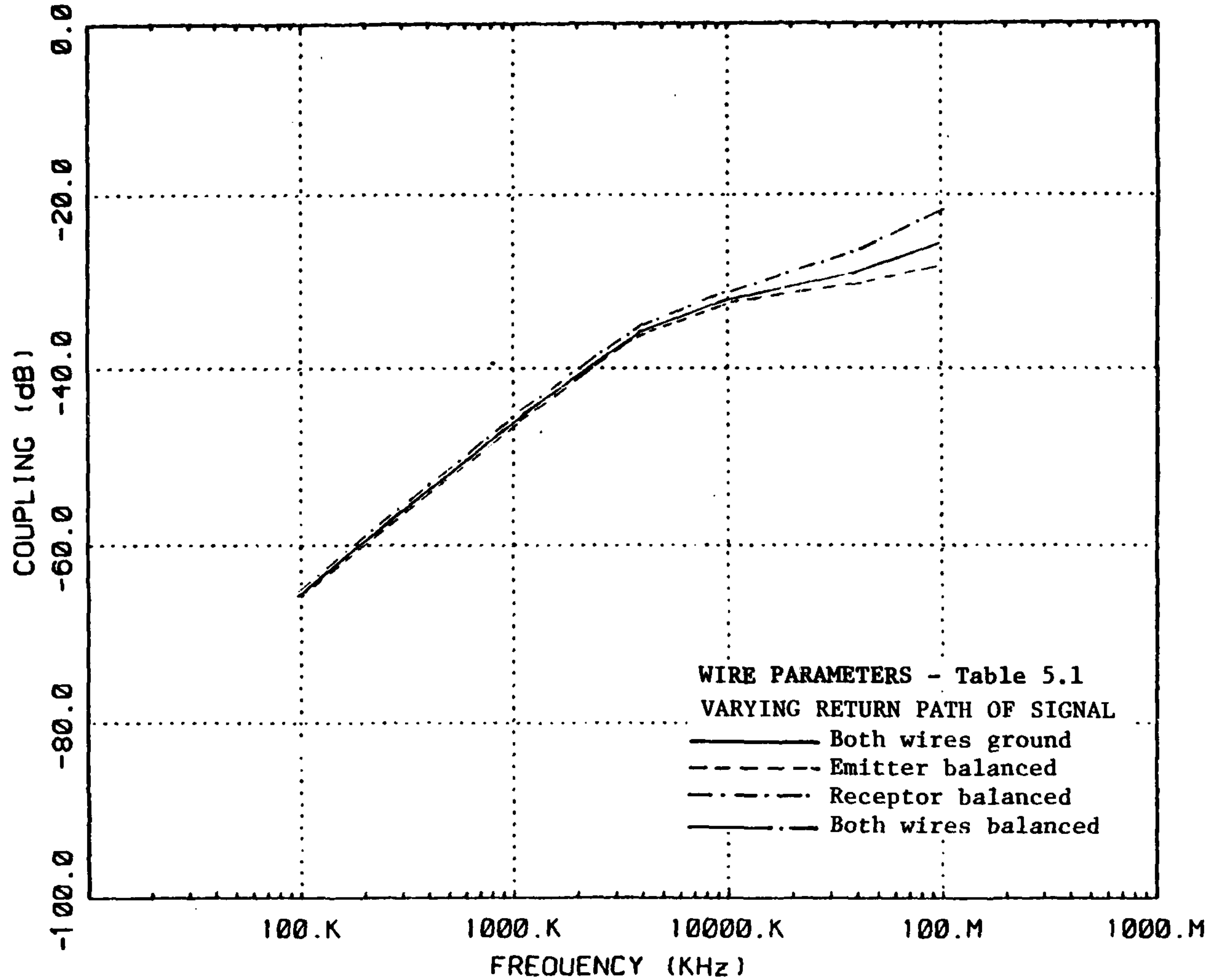


Figure 5.4e

Table 5.6 Coupling Guidelines for Both Wires Single Shielded – Double End Grounded

Parameter Varied	Variation Increment	Coupling Correction (dB)
Average Wire Separation	± 100%	± 6 (100 kHz – 100 MHz)
Segment Height	± 100%	± 3 (100 kMz – 16 MHz) < ± 1 (16 Mhz – 100 MHz)
Segment Length		
• zero pigtail	± 100% (length)	± 7 (100 kHz – 2 MHz)
• 1/8 inch pigtail	± 100% (length)	± 3 (100 kHz – 2 MHz)
• 1/4 inch pigtail	± 100% (length)	± 2 (100 kHz – 2 MHz)
• 1/2 inch pigtail	± 100% (length)	± 2 (100 kHz – 2 MHz)
• 1 inch pigtail	± 100% (length)	± 1 (100 kHz – 2 MHz)
• 3 inch pigtail	± 100% (length)	< 1 (100 kHz – 2 MHz)
Pigtail Length	± 100% (length)	± 5 (100 kHz – 10 MHz)
Return Path		None

- double end grounded

Three different sensitivity calculations were performed:

- variation of average wire separation
- variation of segment height
- variation of segment length

The results of the sensitivity calculations are shown in Figures 5.5a - 5.5c. The guidelines are given in Table 5.7.

The results are similar to previous results obtained when the wire separation, segment height and segment length were varied and the previous discussions apply to this case as well.

5.2.2 Discussion and Recommendations

A series of sensitivity analysis calculations were performed using the wire-to-wire coupling analysis routine from the IEMCAP code. The following wire configurations were analyzed:

- both wires unshielded
- emitter wire single shielded, receptor wire unshielded
- emitter wire unshielded, receptor wire single shielded
- both wires single shielded
- emitter wire unshielded, receptor wire double shielded.

The wires that were used in the analysis (see Table 5.1) were chosen because they are typical wire types in use for the various port types supported by the IEMCAP. Other wire sizes have been covered, at least indirectly, because changing wire size in the analysis has the same effect as (or can be associated with) varying wire separation and segment height. A selected set of parameters important to the wire-to-wire coupling program were systematically varied. The parameters were:

- average wire separation
- wire segment height
- wire segment length
- pigtail length
- shield grounding configuration
- reference wire return path

Wire separations were analyzed from a minimum (touching case) to as much as 11.2 cm. This range of separations provides coupling data on wire bundles consisting of two/three wires in a bundle to bundles of wires with an equivalent bundle diameter of 17.6 inches. These configurations should adequately cover those encountered among "real cables and cable bundles."

The wire segment heights covered the range from touching the ground plane to 5.6 cm (2.2 inches) above the ground plane. For systems such as the XM-1 tank, the wire bundling will be confined very close to the superstructure and "real bundles" in this case will be very close to the ground plane.

The lengths of wires considered may be viewed as short (6 feet), medium (12-24 feet) and long (48 feet) in terms of physical lengths. Electrical lengths of these wires vary considerably with frequency as shown in Table 5.2.

Average wire separation and segment length seemed to be the most sensitive. Average wire separation coupling variations were from 5.5 - 10 dB for each 100% change in the separation parameter. Similar changes in segment length provided a change in coupling of 5 - 7 dB. Important changes were noticed in coupling when shields were double end grounded. Variations in segment length for segments involving double end grounded shields caused

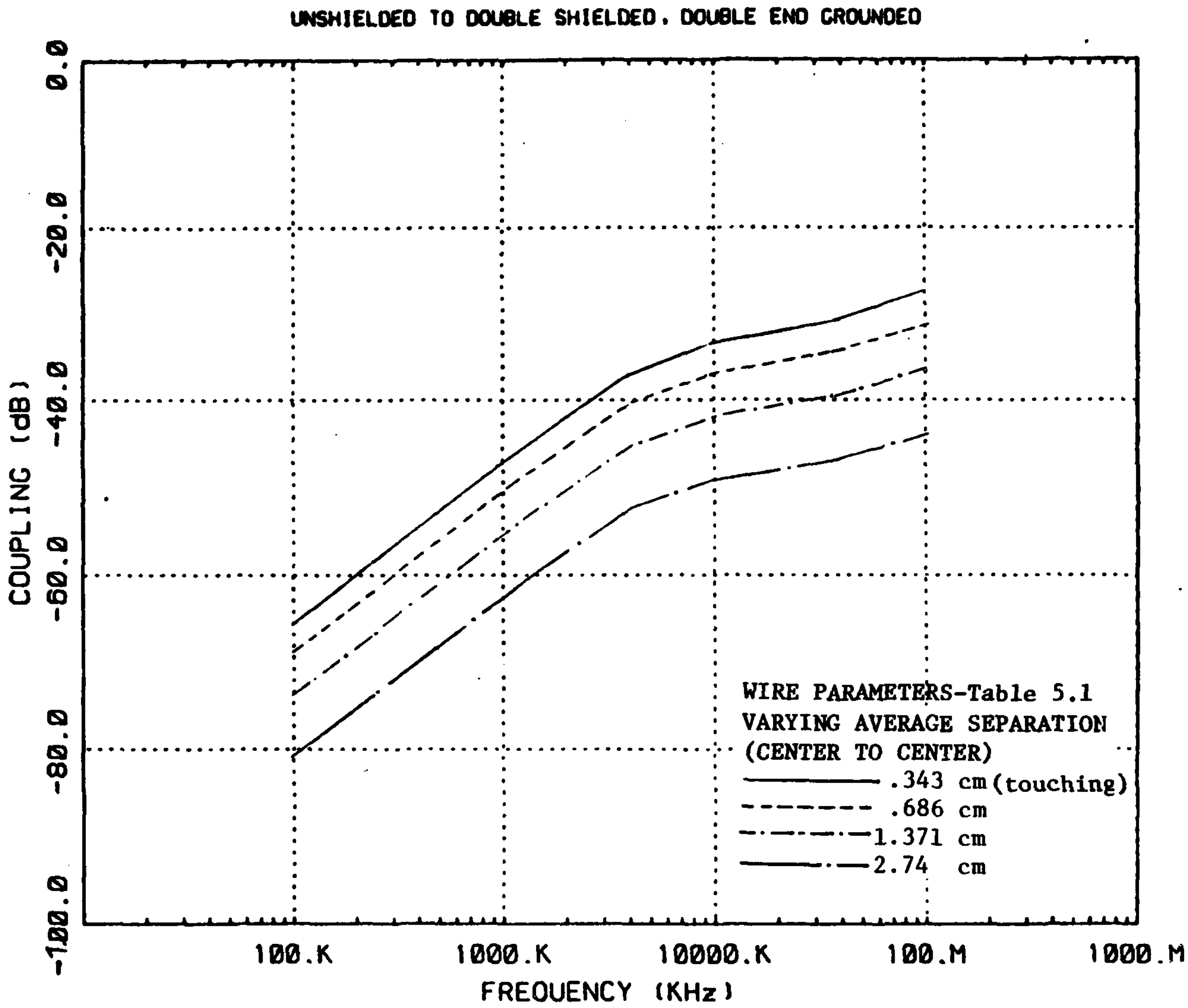

UNSHIELDED TO DOUBLE SHIELDED, DOUBLE END GROUNDED
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING AVERAGE SEPARATION
(CENTER TO CENTER)
.343 cm (touching)
.686 cm
1.371 cm
2.74 cm

Figure 5.5a

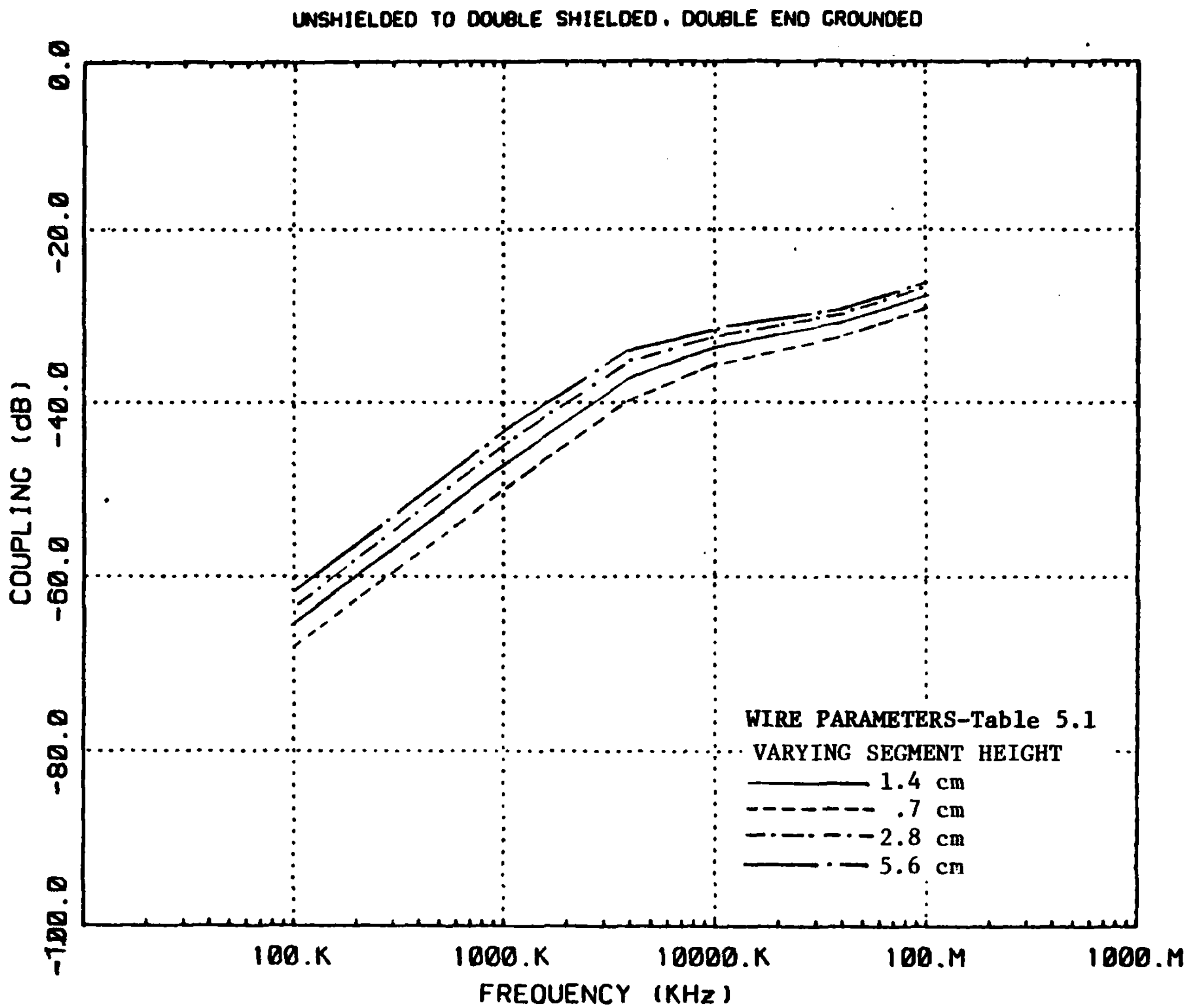

UNSHIELDED TO DOUBLE SHIELDED, DOUBLE END GROUNDED
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT HEIGHT
1.4 cm
.7 cm
2.8 cm
5.6 cm

Figure 5.5b

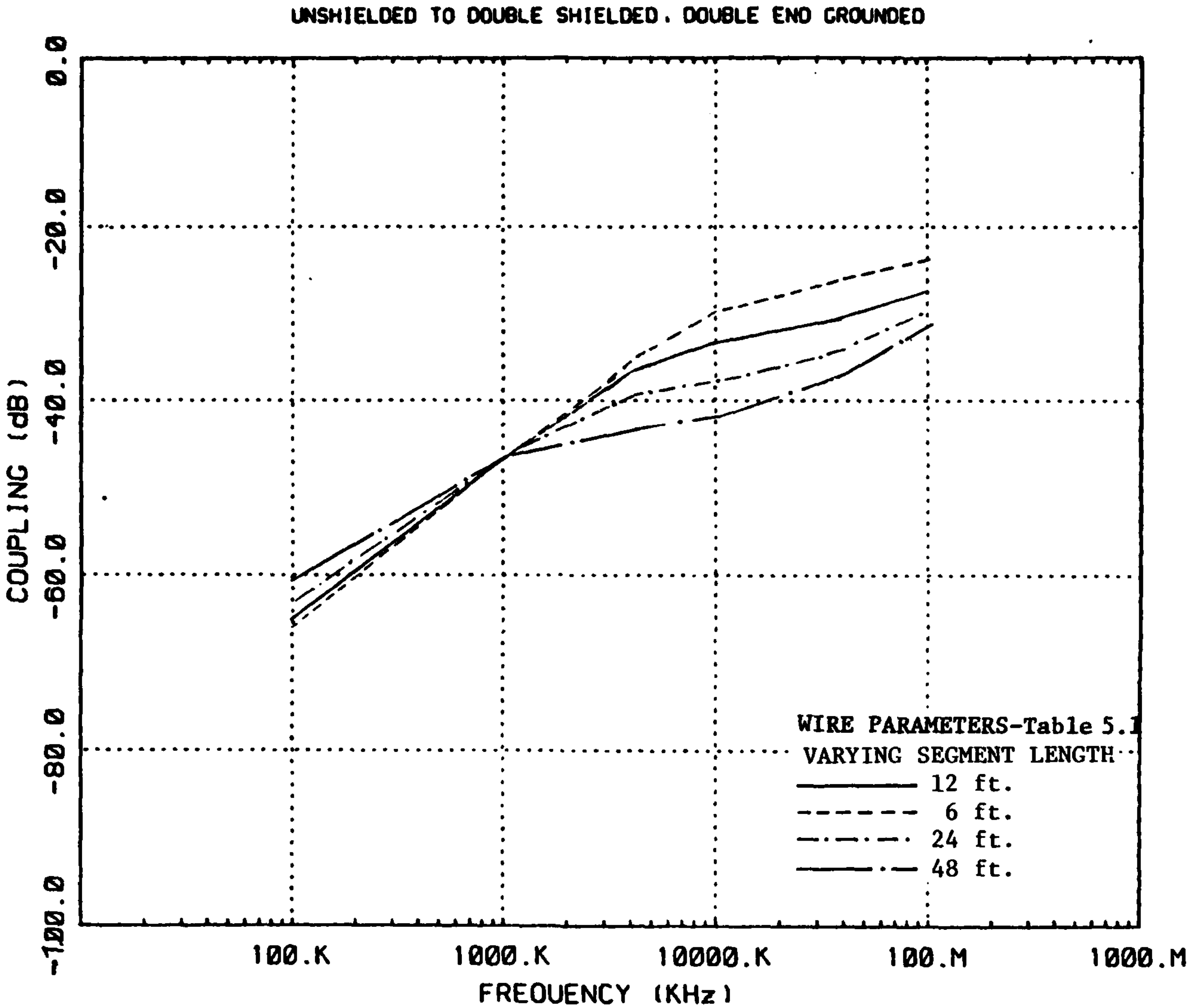

UNSHIELDED TO DOUBLE SHIELDED, DOUBLE END GROUNDED
COUPLING (dB)
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
100.K
1000.K
10000.K
100.M
1000.M
FREQUENCY (KHz)
WIRE PARAMETERS-Table 5.1
VARYING SEGMENT LENGTH
12 ft.
6 ft.
24 ft.
48 ft.

Figure 5.5c

Table 5.7 Coupling Guidelines for the Emitter Wire Unshielded and the Receptor Wire Double Shielded

Parameter Varied	Variation Increment	Coupling Correction (dB)
Average Wire Separtation	± 100%	± 5 (100 kHz - 100 MHz)
Segment Height	± 100%	± 3 (100 kHz - 16 MHz) ± 2 (16 MHz - 100 MHz)
Segment Length	± 100%	± 2 (100 kHz - 2 MHz)

complicated coupling variations including curve crossings and oscillations. The cause of this behavior is not known with certainty but it is suspected that wire model breakdown may be occurring. Additional effort in this area is very desirable.

The wire-to-wire analysis program in IEMCAP uses lumped circuit element models to predict the wire-to-wire coupling. Such models are adequate only for circuits that are electrically small (circuit dimensions << wavelength). In performing the sensitivity analysis, variations in circuit dimensions (e.g., wire length, height) also should be electrically small. This proved to be the case only over certain frequency ranges. Consequently, the guidelines have frequency ranges associated with them.

The wire-to-wire analysis program is restricted currently to one wire segment. A generalization of the code is possible in which a wire could be divided into several segments (each electrically small) and be allowed to have branches. The coupling in each segment and branch would be computed and the total coupling approximated as a sum of the coupling over all segments and branches. In this way an electrically long or complicated wire bundle can be approximated quite well. In future efforts, the program could be expanded to include these capabilities.

The wire-to-wire program was carefully analyzed and several programming errors found and corrected. These corrections have lead to better agreement with experimental wire coupling results than had previously been the case. It is felt that further work in this area is desirable especially in view of the strange results obtained with wires whose shields are double end grounded.

A variable pigtail length was added to the code. The pigtail length can now be any length including no pigtail. The code is still somewhat restricted by the fact that both wires must have the same pigtail length. This restriction could be resolved in a future development effort.

6.0 IMPLEMENTATION OF IEMCAP ANALYSIS INTO THE ARMY SYSTEM DESIGN

Based on the experience with the XM-1, it remains difficult to realistically compare the advantages and disadvantages of having an IEMCAP analysis performed by the prime contractor and/or an independent EMC consultant. Since it was not cost effective to obtain the input data from the prime contractor on the XM-1, it may be advantageous to have certain analysis functions performed by the prime contractor and other analysis functions performed by an independent EMC consultant. In performing this study, the various possible applications of IEMCAP and the various functions that must be accomplished in order to perform an IEMCAP analysis for the Army were considered.

Examples of various possible applications of IEMCAP for the Army include:

- analysis support during the system design to evaluate the overall system EMC;
- analysis support in the generation of EMC specifications and in the evaluation of deviations or waivers;
- analysis support to system EMC testing.

Examples of functions that must be performed in order to implement an IEMCAP type analysis into the Army system design are:

- data collection;
- establishing and maintaining a data base;
- update and maintenance of IEMCAP code;
- development and incorporation of new or improved models into IEMCAP;
- application of IEMCAP to a specific system;
- evaluation and analysis of results.

For each possible application of IEMCAP and for each of the functions that must be accomplished in order to perform an IEMCAP analysis, this study was unable to determine whether the particular application or function can best be performed by the prime contractor, an independent EMC consultant, or some combination of the two. As a result of this study, it is suggested that interfacing with system design contractors to develop a cost effective plan for implementing an IEMCAP analysis into the Army system development cycle be undertaken. If a plan can only be devised

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IEMCAP ANALYSIS OF THE XM-1 TANK.(U)
SEP 82 T E BALDWIN, D R PFLUG, M K BARTLEY DAAK80-81-C-0030
UNCLASSIFIED CECOM-81-0030-F NL

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whereby the availability of system data remains with the prime contractor, then it will probably be more efficient to have the EMC analysis performed by the prime contractor.

In the event that it is determined that a combination of the two is the most cost effective, the plan should define the desired interface between the prime contractor and the independent EMC consultant.

Some of the specific factors that remain to be considered in determining a cost effective plan to perform an IEMCAP implementation are:

- prime contractor's access to certain system data;
- prime contractor's familiarity with system considerations and constraints;
- consultant's expertise with EMC standards, analysis techniques, and IEMCAP;
- consultant is impartial and has no vested interest in the system;
- the ability of a consultant to establish and maintain a large single data base and thus avoid duplication of effort;
- consultant's ability to perform modifications and improvements to code to avoid duplication of effort;
- consultant's ability to provide a degree of standardization rather than having various contractors performing different modifications.

If a satisfactory solution to the problem of obtaining the input data required for an IEMCAP analysis cannot be resolved, then it is suggested that a study be undertaken to tailor an intrasystem analysis program for the Army consistent with their system design procedures.

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2. C. R. Paul, and L. D. Thompson, Revision of the Wire-to-Wire Coupling Subroutine (WTWTFR) in IEMCAP, Prepared for the Air Force Intrasystem Analysis Program, March 1978.

3. Interference Reduction Guide for Design Engineers, Vol I, FILTRON Co. Inc., Flushing N.Y. Contract DA36039SC90707, AD-619666, 1 August 64.

4. Interference Reduction Guide for Design Engineers, Vol. II, FILTRON Co. Inc., Flushing N.Y. Contract DA36039SC90707, AD-619667, 1 August 64.

APPENDIX I

THE INTRASYSTEM EM COMPATIBILITY ANALYSIS PROGRAM (IEMCAP)

1. Introduction

The Intrasystem Electromagnetic Compatibility Analysis Program (IEM CAP) was designed to provide an effective and cost beneficial means of EMC analysis throughout the stages of an Air Force system's life cycle from conceptual studies of new systems to field modification of old systems. Ground, aircraft, and space/missile systems are within the IEMCAP capability. The program is relatively computer independent and has been implemented on CDC, Honeywell, IBM, Univac and Xerox computers. It is programmed in USA standard FORTRAN IV language and requires approximately 74K words of main memory.

IEMCAP analysis demonstrates the relationship between equipment and subsystem EMC performance and total system EMC characteristics in specific terms. It therefore provides the means for tailoring EMC requirements to the specific system. This is accomplished by modeling the system elements and the mechanisms of electromagnetic energy transfer to accomplish the following tasks:

a. provide a data base that can be continually maintained and updated to follow system design changes;

b. generate EMC specification limits tailored to a specific system;

c. evaluate the impact of granting waivers to the tailored specifications;

d. survey a system for incompatibilities;

e. assess the effect of design changes on system EMC; and

f. provide comparative analysis results on which to base EMC trade-offs decisions.

2. Data Organization

The data base that supports the IEMCAP analysis is hierarchical in structure relating the system, subsystem and equipment levels of system organization. For example, a Ground Controlled Approach (GCA) system would be composed of radar, communications, computer and display subsystems which are, in turn, composed of "black boxes" or equipments, consisting of transmitters, receivers, antennas, control units, multicouplers, etc. EM energy is transferred in and out of these equipments via "ports". These ports may be intentional or unintentional. For example, an equipment case with poor shielding integrity is an unintentional port, whereas a power cable that exits an equipment is an intentional port.

3. Analysis Approach

Intentional ports have intended functions to perform. The operationally required signals or responses associated with these functions are intentionally generated and cannot be altered without affecting system operation. In addition to the required signals, undesired non-required outputs and/or responses may exist. Examples of non-required signals include harmonics and spurious emissions or spurious responses.

An EM incompatibility is determined to exist when an interfering signal from an emitter port, or ports, is coupled to a receptor port through any path and is large enough to exceed the susceptibility threshold. The limits for non-required signals are defined in EMC specifications. An important task of IEMCAP is the generation of a set of specification limits tailored to the specific system under analysis.

The emissions and susceptibilities, both required and non-required,

are represented in IEMCAP by spectra (frequency versus amplitude characterizations). For each emitter port a two-component (broadband and narrowband) spectrum represents the power levels produced over the frequency range. The broadband component consists of noiselike or largely unintentional emissions that are fairly constant over wide frequency ranges, whereas the narrowband component is usually well defined within a limited frequency range. The broadband components are in units of power spectral density. The narrowband components are in units of power.

For each receptor a spectrum represents its susceptibility threshold versus frequency characteristic. This susceptibility standard threshold is the level of minimum received signal which produces a standard response at a given frequency.

A required frequency range is defined for each intentional port. Signals within this range are those required for operation and therefore not adjustable for EMC purposes. Outside this range specified limits may be established for the maximum emission and minimum susceptibility levels. The spectrum within the required range can be defined by a mathematical model. This is done by using the theoretical equations of the frequency domain representation of the signal or may be input as a user-defined spectrum.

The specification generation process adjusts these assumed spectrum levels to achieve compatibility if interference is indicated. By readjusting the spectra of emitters and receptors, the maximum non-required emission and minimum susceptibility levels are obtained for a compatible system. To prevent overly stringent specifications from being generated, each spectrum has an adjustment limit.

In order to initiate the process, IEMCAP uses the limits of military EMC specifications MIL-STD-461A and MIL-I-6181D or a modification thereof. The user has the option of adjusting these at his discretion. These specifications are involved because of their wide application at the

equipment level and most EMC engineers are familiar with them. This philosophy also helps to assure that, if new equipments are added to a system containing existing equipment developed and tested to these specifications, the IEMCAP-generated specifications will be at the same general levels and not result in radical changes in EMC design. It also facilitates adapting an equipment from one system to another system.

The process is a sequence consisting of selection of an emitter port and a receptor port and then examining the type, connection, location, wire routing, etc., to determine if a coupling path exists. If a path does exist, the received signal is computed at the receptor and compared to the susceptibility level. In addition to the emitter-receptor port pair analysis, the program also computes the total signal from all emitters coupled into each receptor acting simultaneously.

A sampled spectrum technique in which each spectrum amplitude is sampled at various frequencies across the range of interest is used. MIL-STD-461A requires three sample frequencies per octave from 30 Hz to 18 GHz, providing approximately 90 sample frequencies. This degree of resolution appears reasonable for EMC specifications since the limits of emission and susceptibilities are fairly constant over large regions of the spectrum. Additionally, none of the individual requirements cover the total frequency range, so much less than 90 data points per spectrum may be used. If greater resolution is desired, IEMCAP allows the user to specify levels at individual frequencies. In addition, IEMCAP samples the spectrum in the interval half-way between the sample frequency and each of its neighboring sample frequencies in order to avoid missing narrow peaks or nulls between sample frequencies. The maximum level in the interval is used for emission spectra, and the minimum level is used for susceptibility spectra. This quantizes the spectra with respect to the sample frequencies in a worst case direction. A table of sample frequencies is defined for an equipment, and all spectra of ports within that equipment utilize these frequencies.

The user has two options with respect to the equipment frequency

table. He may specify the upper and lower frequency limits, the maximum number of frequencies to use, and the number of frequencies per octave. The program will then generate a table of geometrically spaced frequencies within the specified limits. Optionally, he may specify the upper and lower frequency limits, the maximum number of frequencies, and a number of specific frequencies of interest. The program will then generate geometrically spaced frequencies to fill in the number of frequencies not specified. The program will accept any range from 30 Hz to 18 GHz, but if desired, the user may concentrate all 90 frequencies over a smaller interval within this range.

Each port is categorized into one of six types (based on function). Each type has its own range of frequencies within the overall frequency range. These ranges, adapted from MIL-STD-461/462 ranges for the port function, are shown in Table I-1. The non-required spectrum model assumes zero emission and susceptibility outside these ranges. The quantized spectra and amplitudes within up to 90 contiguous intervals across the frequency range of interest is thus generated by the program.

TABLE I-1

PORT EMISSION AND SUSCEPTIBILITY TESTS AND FREQUENCY RANGES

PORT FUNCTION	EMITTER		RECEPTOR	
	MIL-STD-462 Test (s)	Freq Range (Hz)	MIL-STD-462 Test (s)	Freq Range (Hz)
RF	CE06	14K-18G	CS04	14K-18G
Power	CE02/03	30-50M	CS01/02	30-400M
Signal	CE02/04	30-1G	CS02/04	30-10G
Control	CE02/04	30-1G	CS02/04	30-10G
EED	-------	-------	CS02/04	30-10G
Eqpt Case	RE02	14K-10G	RS03/04	14K-10G

This representation allows the program to be divided into two sections, each running in approximately 74K (decimal) of main memory. One section of the program contains the input data management and spectrum model routines (IDIPR), and the other contains the analysis and transfer model routines (TART). Each section is executed separately so that both are not in memory at the same time. This provides a flexible program, readily adaptable to a wide variety of computers. Machine-dependent techniques, such as overlaying, are not used.

The maximum system size per computer run is shown in Table I-2. For each equipment, the 15 ports include the case leakage. Therefore, 14 intentional ports are allowed.

TABLE I-2

MAXIMUM SYSTEM SIZE

EQUIPMENTS	40
PORT PER EQUIPMENT	15
TOTAL PORTS (40 x 15)	600
APERTURES	10
ANTENNAS	50
FILTERS	20
WIRE BUNDLES	140
TOTAL NUMBER OF WIRES	280
BUNDLE POINTS PER WIRE	11
BUNDLE SEGMENTS	140

4. IEMCAP Operation

The Input Decode and Initial Processing Routine (IDIPR) is the first part of IEMCAP. It is divided into three basic routines. The Input Decode Routine (IPDCOD) reads and decodes the free-field input data from punched cards and checks the data for errors. Next, the Initial Processing Routine (IPR) performs the data management, interfaces with the spectrum models and generates the working files. The data base defining the total system characteristics is stored on a magnetic tape or disc file called the Intrasystem Signature File (ISF). The program then enters the Wire Map Routine which generates cross-reference map arrays for use by the wire coupling math models during analysis. At this point, the IDIPR provides summary data for the system, as requested by the user, and execution then terminates.

The second portion of IEMCAP, called the Task Analysis Routine (TART) uses the data via the working files provided by IDIPR to perform one of the four analysis tasks listed below.

a. Specification Generation - This subroutine can adjust, within specified limits, the initial non-required emission and susceptibility spectra, attempting to make the system compatible. A summary of interference conditions is printed.

b. Baseline System EMC Survey - The appropriate routine analyzes the system for interference. If the maximum of the EMI point margins over the frequency range for a coupled emitter-receptor pair exceeds the user specified printout limit, a summary of the interference is printed. Total received signal into each receptor from all emitters is also printed.

c. Trade-Off Analysis - This analysis task compares the interference from two EMC analysis runs. The effect on interference of antenna changes, filter changes, spectrum parameter changes, wire

changes, etc., can be assessed from this analysis.

d. Specification Waiver Analysis - The waiver analysis task allows adjustments to selected port spectrums (often to represent a waiver request) and evaluates the impact of this change.

5. Emitter Models

The emitter models relate the parameters of the equipment and port data to the power spectral density output at the emitter port. Many emitter models are incorporated in the program in the SCARFE routine for common emitter types, and provision is made for user input of spectral densities for those types not modeled. A few of the emitter models are listed below:

a. Analog modulation representations, such as AM, AM/DSB/SC, SSB, and FM, either voice, clipped voice, or non-voice.

b. Digital modulation representations, such as PDM, PCM/AM, PPM/AM, PAM/FM, or binary FSK.

c. Pulse modulation representations (rectangular, trapezoidal, triangular, Guassian, Chirp, damped sinusoid, sawtooth, exponential, etc.).

d. CW

The user has the option of augmenting the emitter models with selected filter functions.

6. Receptor Models

The basic approach for RF receptors used in IEMCAP is to accept input data on in-band sensitivity, along with a bandwidth parameter, and then to form a susceptibility function in the required spectra defined by

user-adjusted military specification interference limits as designated. An RF receiver representation in the program will, in general, have a trapezoidal shaped susceptibility function (in band) due to the skirt slopes of the normal selectivity curve. The susceptibility of an RF port is assumed to be equal to the nominal tuned sensitivity of the receiver, as provided in the input data, over the entire frequency range defined by the user-specified bandwidth. The susceptibility of a signal or control port is to be equal to the operating level, less 20 dB. This somewhat arbitrary susceptibility level is based on characteristics of common avionics equipments. The user may define a higher or lower susceptibility level in the required range of a signal or control port by specifying a higher or lower operating level.

In the case of receivers where more is known about the details of the response curve than just the flat response discussed above, the user can specify the known response curve by a discrete spectrum of up to ten frequencies with associated levels. The user has an additional option of augmenting the receptor models with selected filter functions. The filter models modify the levels of a given emitter signal at the receptor by the level at the filter output terminals for compatibility analysis.

7. Transfer Models

The transfer models are designed to compute the ratio (path loss) between the energy output at an emitter port and that present at the input to a receptor port. For example, the antenna-to-antenna transfer model computes the ratio of the energy output of a transmitter to the energy at the input of the receptor. Receptor models then relate the energy spectrum at the receptor port to the response produced by that spectrum. This latter calculation is based on the susceptibility-versus-frequency response of the receptor.

8. Filter Models

Seven filter models are used in IEMCAP: single tuned, transformer

coupled, Butterworth tuned, low pass, high pass, and band reject. The models represent filters as ideal, lossless networks, made up only of reactive elements (capacitors and inductors). The filter transfer models calculate the insertion loss in dB provided by a filter at a given frequency, i.e., the reduction in delivered power due to insertion of a filter along with a limit or "floor" to more accurately represent actual filters. Provision is made for the entry of a minimum insertion loss to represent the effect of the filter at the tuned frequency or in the pass band.

9. Antenna Model

Antennas are categorized into two groups. The first group includes low gain antenna types such as a monopole, dipole, slot or loop antennas. Antennas included in the second groupare medium to high gain types, such as those using horns or parabolic reflectors. All antennas in the first group are modeled analytically by trigonometric expressions. A dipole, for example, has a directive gain $G_d = 1.6 \sin^2 \theta$, where θ is the angle of an arbitrary arbitrary direction with respect to the dipole axis. All antennas in the second group are modeled by a three dimensional three-sector/two-sector representation. Each sector subtends a solid angle in the unit sphere and has an associated antenna gain level. The user may use two or three levels at his discretion.

10. Antenna-to-Antenna Coupling

Far-field coupling between antennas located above a ground plane is analyzed using a Simplified Theoretical Ground-Wave Model. A smooth, curved earth is assumed, with the model treating both direct and reflected effects. The model includes the line-of-sight, diffraction, and tropospheric regions. Coupling between antennas aboard an aircraft or spacecraft is analyzed using an Intravehicular-Propagation Model that takes into account vehicle geometry to compute shading and diffraction losses.

11. Field-to-Wire Coupling

Coupling from environmental electromagnetic fields to wiring usually occurs via fields entering through dielectric apertures in the system's skin and coupling to immediately adjacent wires. Exposed wires are assumed to be adjacent to the aperture, and the amount of RF energy coupled is determined as a function of aperture size and location. A transmission line model is then used to compute the currents induced in the wires. Worst-case electromagnetic field vector orientation is determined and used for the calculation.

12. Wire-to-Wire Coupling

If a wire connected to an emitter port is in the same bundle as a wire connected to a receptor port, the wire-to-wire coupling routine is called. This routine computes the spectral voltages induced in the receptor circuit by the emitter circuit. These calculations are performed on a pair basis (only one emitter circuit considered to couple with the receptor circuit for each calculation), with the effects of all other circuits neglected during this calculation. Each possible pair coupling is computed, and the total coupling is calculated by summing all of the maximum pair couplings over the interval without regard to phase. The validity of this wire-to-wire coupling model has been verified by experimental data.

13. Case-to-Case Coupling

This routine calculates coupling between cases in the system. The case is considered a point at its center. The model assumes a dipole antenna with $1/r^3$ field falloff.

14. System Model

The system model is used to relate the manner in which the emitter, transfer and receptor models are combined. It is designed to account for

simultaneous operation of all equipments. This enables calculations for compatibility and specification generation to be performed, not only between pairs of equipments, but also among all equipments when more than one equipment operates simultaneously.

15. System/Subsystem Specification Generation

The Specification Generation Routine (SGR) attempts to adjust the non-required portions of the port spectra, initially computed in IDIPR, to produce a compatible system. These spectra are considered limits. Thus an emitter cannot generate outputs greater than the non-required spectrum levels, and a receptor cannot respond to received signals less than these levels, or interference will result. For the analysis, each port is initially assumed to emit and receive at these levels. For each emitter-receptor port pair in the system with a coupling path between them, the received signal is computed using the assumed maximum emission levels. This signal is compared to the assumed minimum susceptibility levels over the frequency range. Where the susceptibility level is exceeded in the emitter non-required range, the emission levels are reduced such that the margin is equal to the user-defined adjustment safety margin or to the adjustment limit level, whichever is greater.

After each emitter has been adjusted in conjunction with each receptor, the receptor spectra are adjusted. The received signal from each emitter with a coupling path to a given receptor is computed using the adjusted emission spectra and summed. The susceptibility spectrum levels are then compared to this total signal, and where the level is exceeded in the non-required range, the susceptibility is raised such that the margin is equal to the user-defined adjustment safety margin or to the adjustment limit level, whichever is less.

This process provides a set of port spectra specifications such that the system will be compatible if they are not exceeded. These become EMC specification limits to which the equipment ports can be tested.

After the adjustment process, a number of port pairs may exist which are still incompatible. This unresolved interference results from required emissions and responses, non-required spectra adjusted to their limits, and from non-adjustable spectra of previously procured equipments. Consequently, after receptor adjustment, SGR recomputes the interference between adjusted emitters and adjusted receptors. If the maximum of the EMI point margin exceeds a user specified limit, the case is printed out as unresolved interference along with a summary of the spectrum levels and the EMI margins.

16. Outputs

A variety of outputs are provided by IEMCAP, the major outputs include:

a. Intrasystem Signature File Report - a data base summary that includes a printout of system and equipment characteristics, as well as equipment frequency tables and spectra.

b. Specification Generation Outputs - Outputs are provided for the three phases of the Spec Generation Routine: an Adjusted Emitter Spectra Summary, a Receptor Spectrum Summary Adjustment and an unresolved Interference Summary. After these, the final adjusted spectra are summarized for each port.

After a given receptor port has been adjusted, the Spectrum Generation Routine scans through the emitters coupled to it and computes the margins. If the maximum margin exceeds the user specified printout limit, a partial summary is printed. Printouts can also be provided for baseline system EMI survey outputs, trafe-off, and waiver outputs.

c. Baseline System EMC Survey Outputs - This output summarizes the conditions of coupling for the relevant frequencies of cases where the maximum EMI margin exceeds the margin print limit.

d. Trade-off and Waiver Outputs - These outputs are similar to the baseline survey outputs, except margin changes are listed when applicable.

e. Supplemental Outputs - Details of the Antenna-to-Antenna, Antenna-to-Wire, and Wire-to-Wire coupling routines can be provided by calling for special outputs. For example, the supplement output for Antenna-to-Antenna coupling provides location coordinates, main beam angles, look angles, and antenna gains. Path loss parameters, and the frequency-dependent loss characteristics are then presented. The same level of details are furnished for the other routines.

APPENDIX II

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